MATLAB EXPO

Date, 2024 | Beijing

使用MATLAB和Simulink开发城市空中交通飞行器

周玲, MathWorks

(Pronoun/Pronoun)

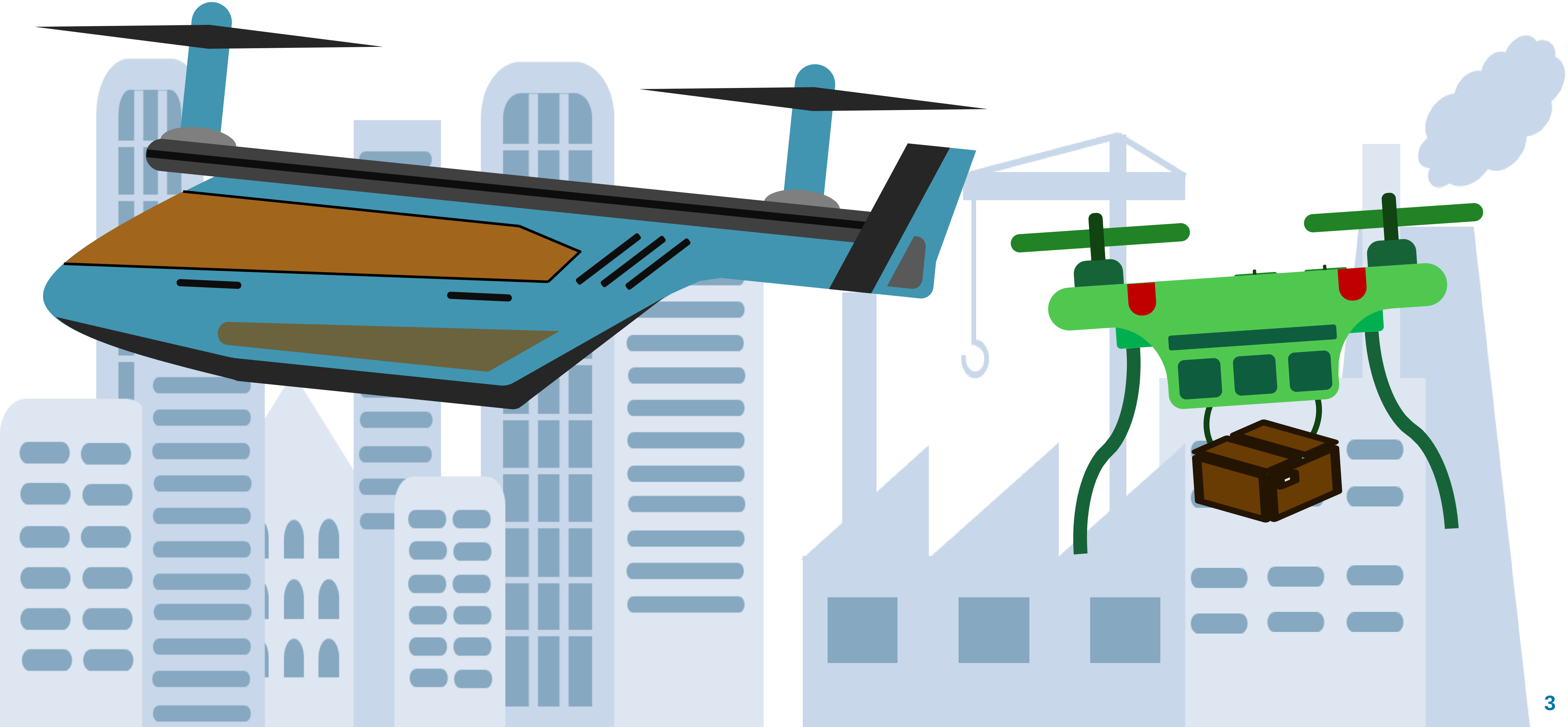
MathWorks

城市空中交通（UAM）

- UAM应用趋势：
  - 创新的移动系统开发
  - 注重安全性和可靠性
  - 利用人工智能、大数据和物联网
  - 研究、开发和运营中的数字化转型

城市空中交通集成了自主性和智能性，以确保安全性和可靠性，同时保持效率

城市空中交通：城市交通的未来



用于城市空中交通的集成工作流程

MATLAB® Simulink®

System Architecture

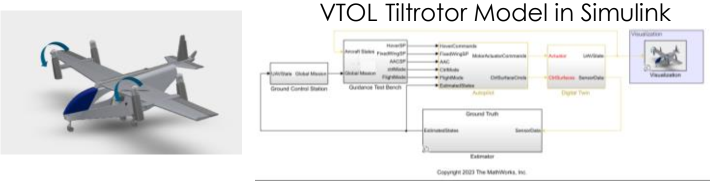
Verification & Validation

87.5%

DO-178

Platform Modeling

VTOL Tiltrotor Model in Simulink



Algorithm Design

Perception

Control

Planning & Decision

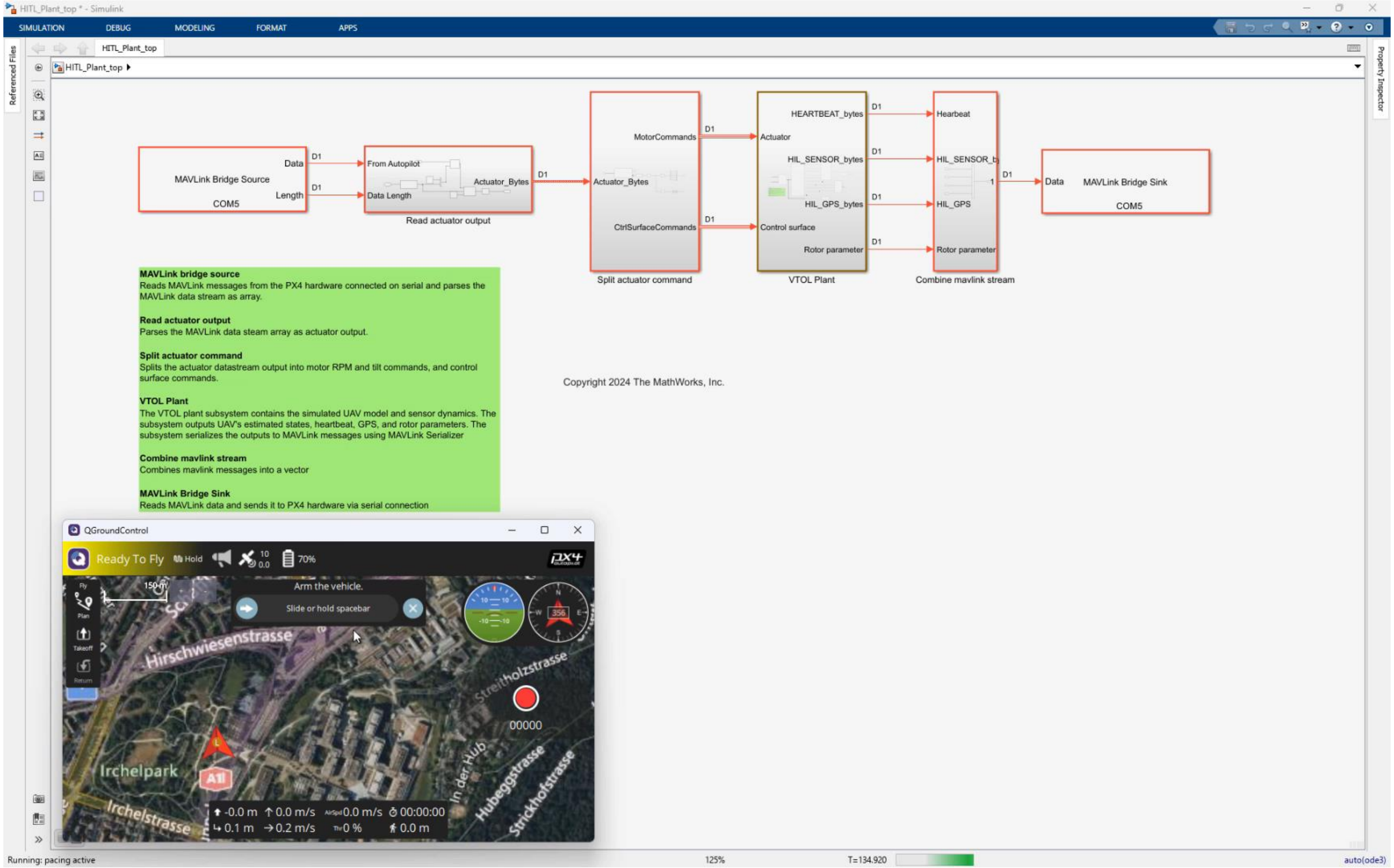
Simulate & Test

Ref. Supernal and MathWorks Joint POC Demo

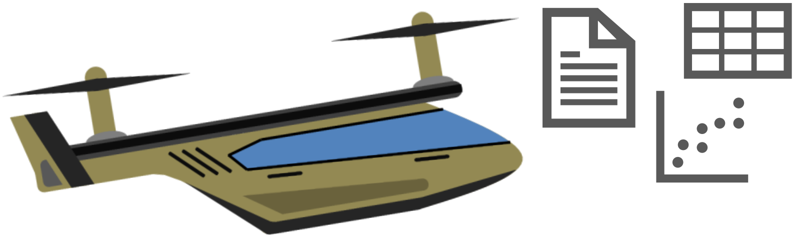
Data Analysis

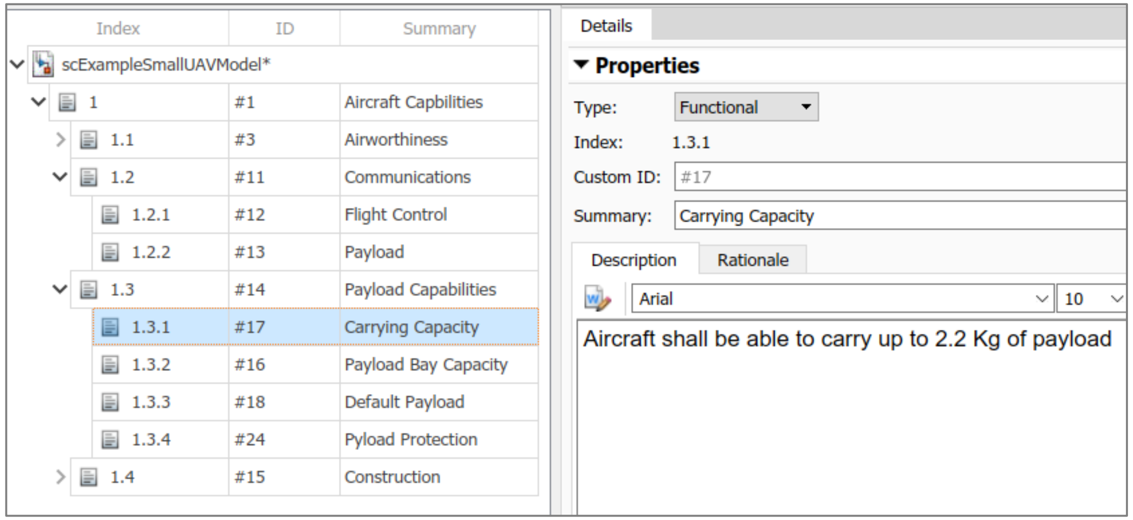
Implement

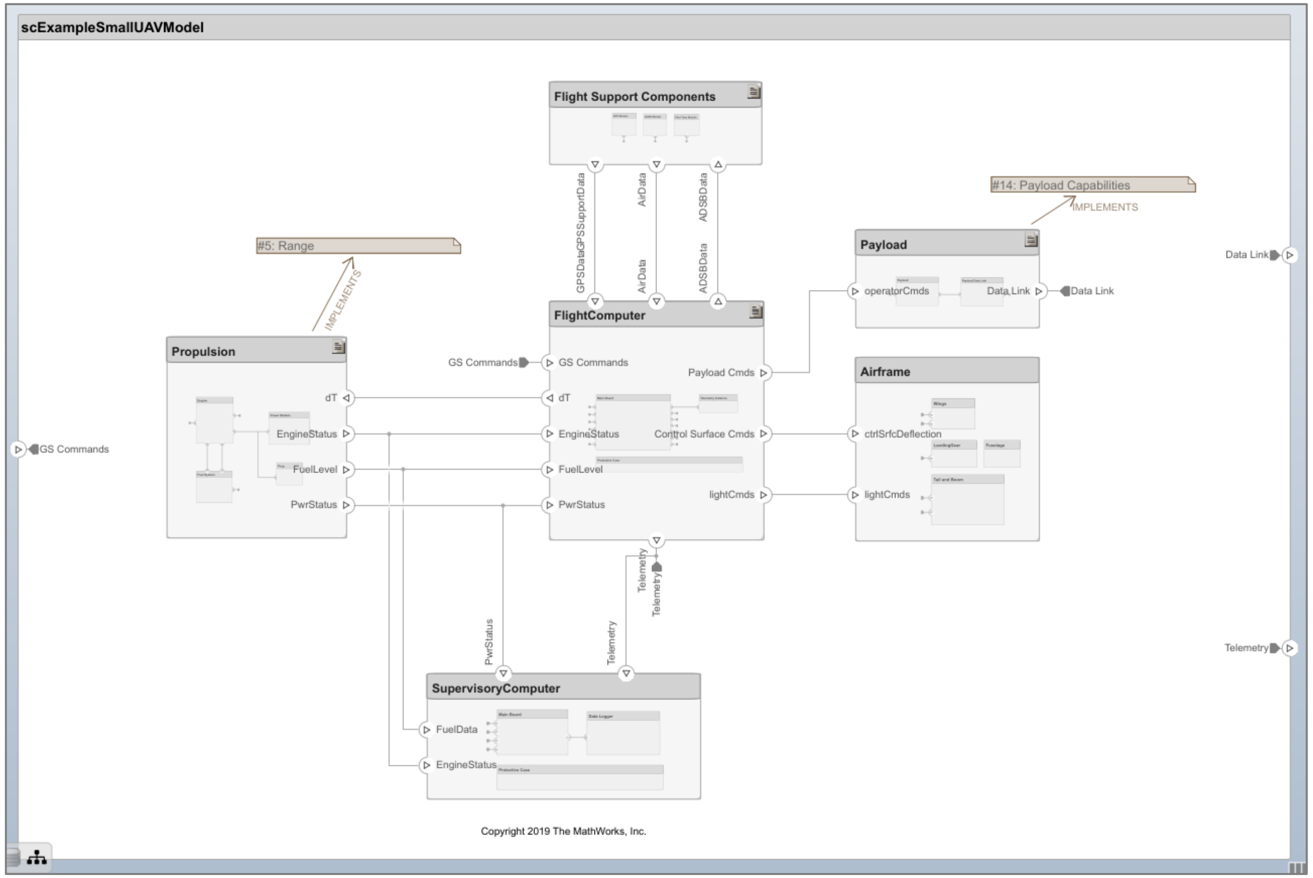
Production Deployment


HITL_Plant_top * - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
HITL_Plant_top
Data
MAVLink Bridge Source
COM5
Length
From Autopilot
Data Length
Actuator_Bytes
Read actuator output
MotorCommands
Actuator_Bytes
CtrlSurfaceCommands
Split actuator command
Actuator
Control surface
HEARTBEAT_bytes
HIL_SENSOR_bytes
HIL_GPS_bytes
Rotor parameter
VTOL Plant
Hearbeat
HIL_SENSOR_b
HIL_GPS
Rotor parameter
Combine mavlink stream
Data
MAVLink Bridge Sink
COM5
MAVLink bridge source
Reads MAVLink messages from the PX4 hardware connected on serial and parses the MAVLink data stream as array.
Read actuator output
Parses the MAVLink data steam array as actuator output.
Split actuator command
Splits the actuator datastream output into motor RPM and tilt commands, and control surface commands.
VTOL Plant
The VTOL plant subsystem contains the simulated UAV model and sensor dynamics. The subsystem outputs UAV's estimated states, heartbeat, GPS, and rotor parameters. The subsystem serializes the outputs to MAVLink messages using MAVLink Serializer
Combine mavlink stream
Combines mavlink messages into a vector
MAVLink Bridge Sink
Reads MAVLink data and sends it to PX4 hardware via serial connection
Copyright 2024 The MathWorks, Inc.
QGroundControl
Ready To Fly
Hold
70%
Arm the vehicle.
Slide or hold spacebar
Hirschwiesenstrasse
Irchelpark
Irchelstrasse
Streitholzstrasse
Hubeggstrasse
Strickhofstrasse
00000
Running: pacing active
125%
T=134.920
auto(ode3)

系统工程







Author, manage, and link requirements

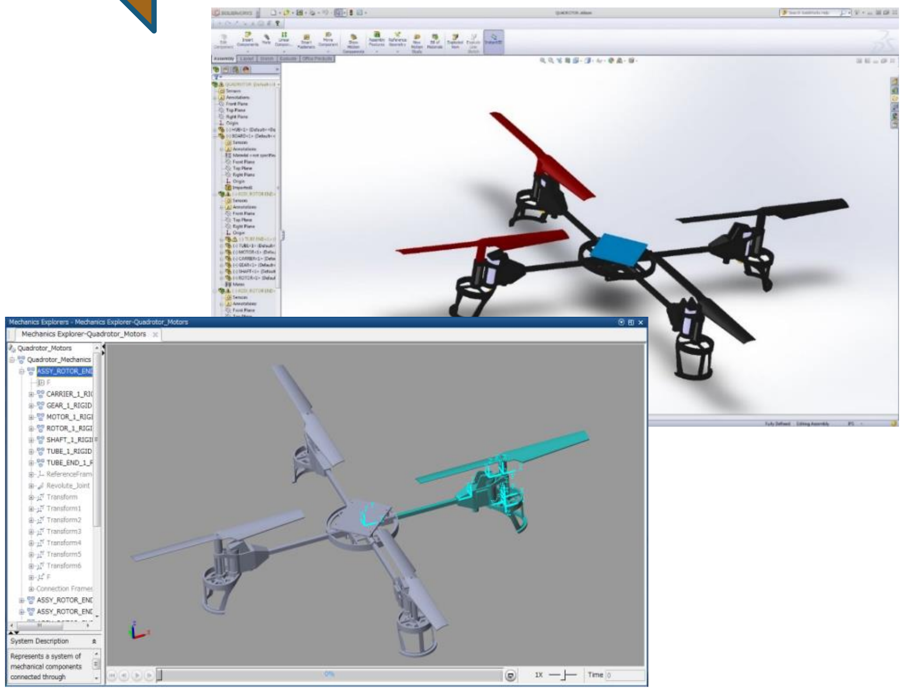
Model system architectures and perform system analysis

平台设计

根据您的任务选择合适的无人机建模方法

高细节
无人机开发

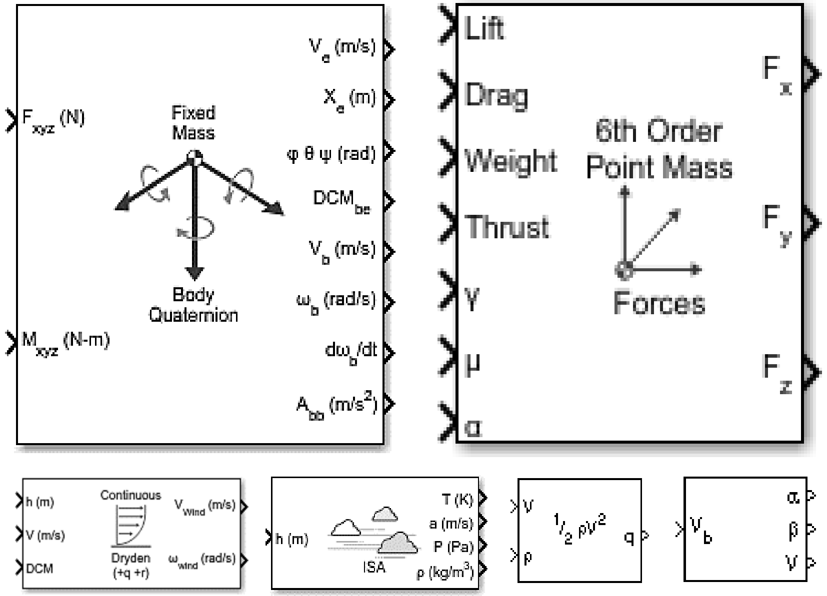
近似
无人机应用



Physical Modeling Link

Model construction techniques and best practices, domain-specific modeling, physical units

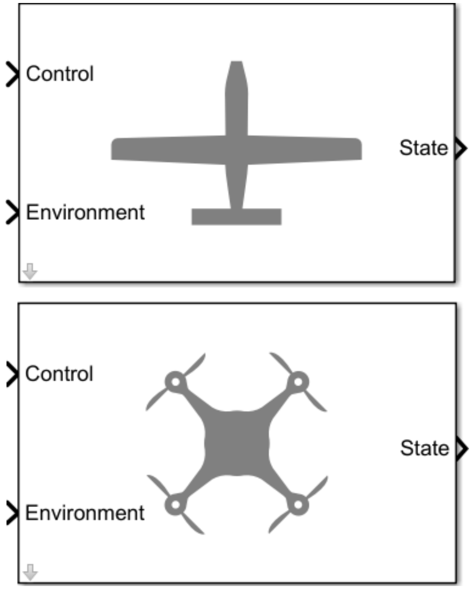
Simscape



Vehicle Dynamics Link

Model aerodynamics, propulsion, and motion of aircraft and spacecraft

Aerospace Blockset



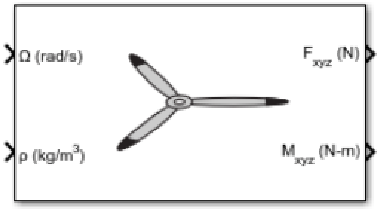
Guidance Model Link

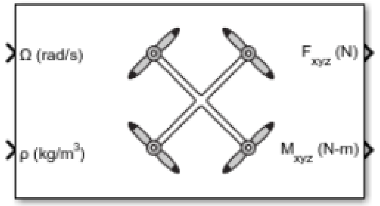
Reduced-order model for UAV

UAV Toolbox

VTOL
仿真旋翼机

旋翼和多旋翼块





Compute the aerodynamic forces and moments generated by one or more rotors.
Aerospace Blockset / Propulsion

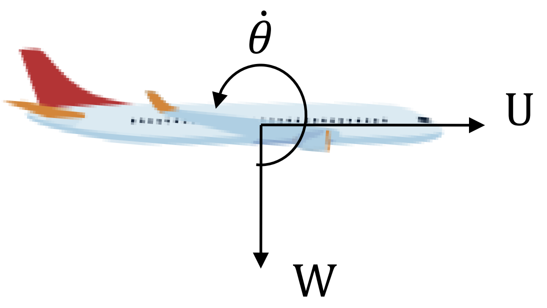
Example:

[Mars Helicopter System-Level Design]

Unreal Engine®旋翼机资产，用于可视化

动力学建模仿真

根据自由度选择合适的被控对象模型
示例：仅考虑纵向 （U、W、θ） 的 3 个自由度→



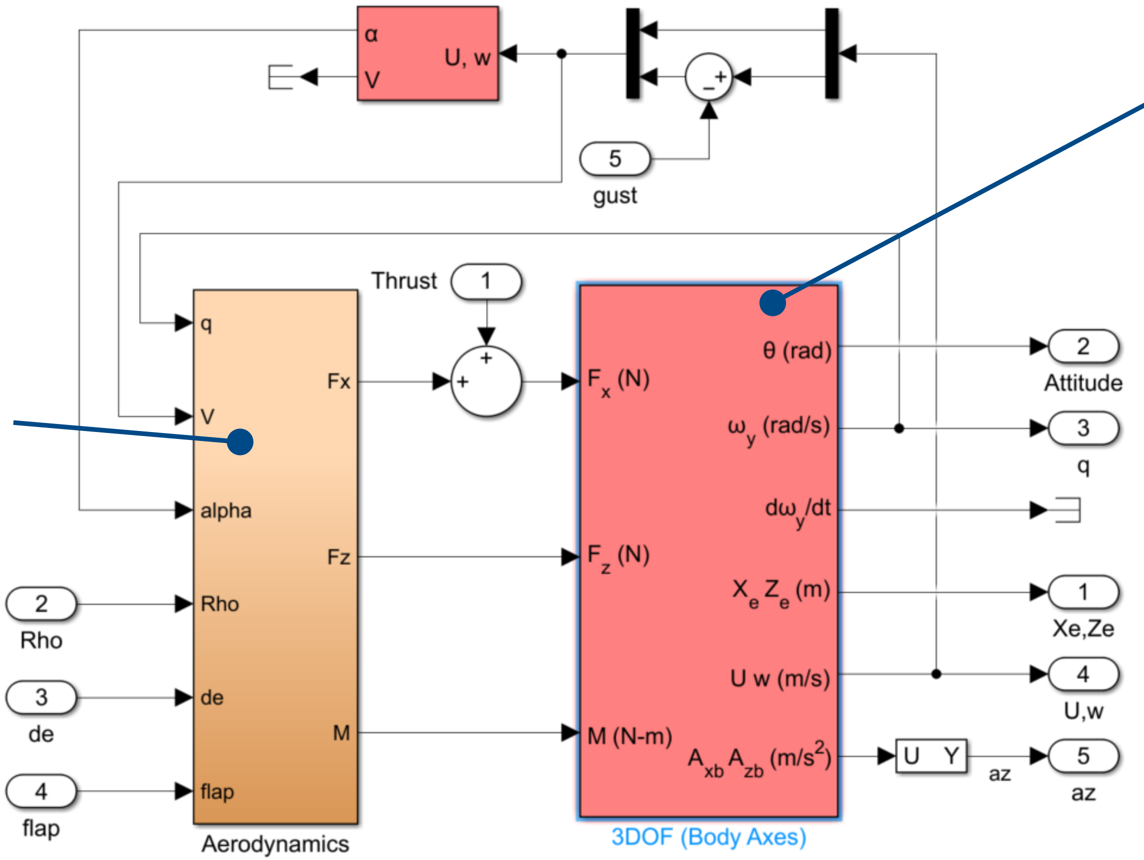
平移：

$$ma = F$$

滚转：

$$I\dot{\omega} = M$$

计算由空气动力学、重力、风力、人为力等产生的每个轴向的力和围绕每个轴的力矩



位置、速度、欧拉角、角速度等的输出

例

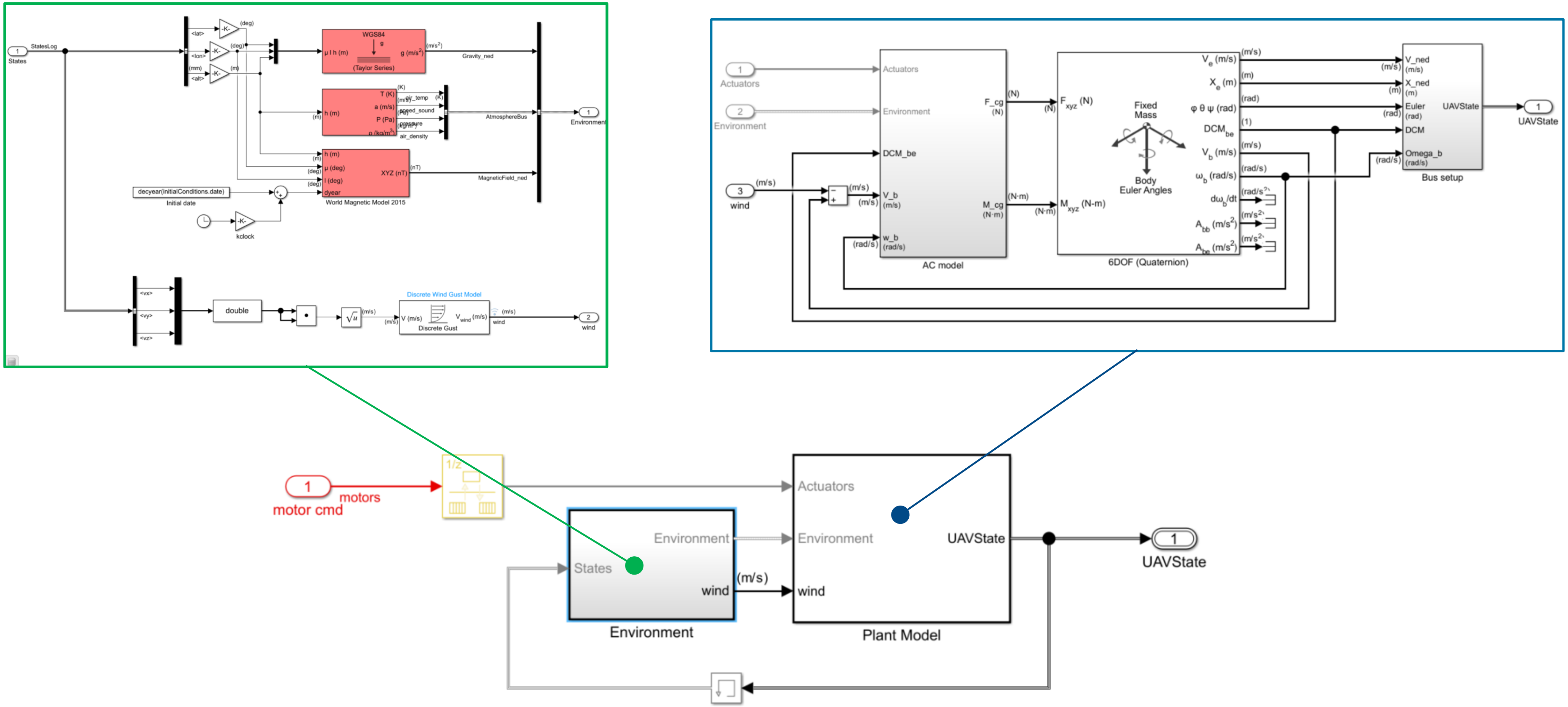
升力：$L = \frac{1}{2}\rho V^2 S C_L$

阻力：$D = \frac{1}{2}\rho V^2 S C_D$

Aerospace Blockset™ 建模示例

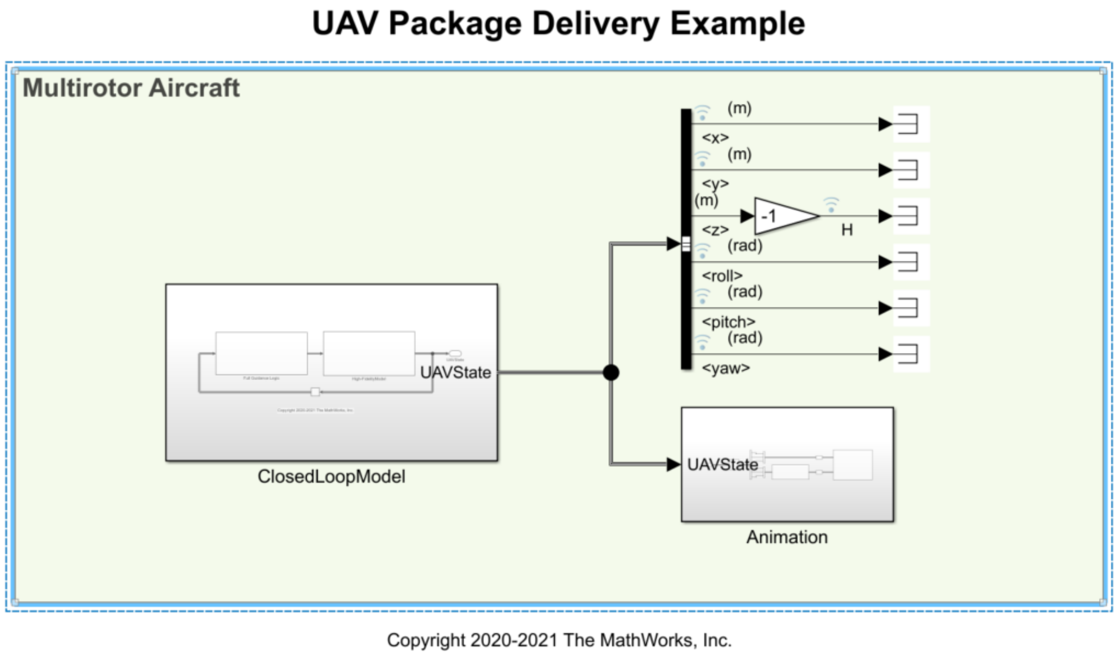
重力、标准大气压、磁力、风等

推力系统、空气动力学、平移和旋转运动、传感器等



环境和机身的六自由度非线性运动模型

仿真实例


UAV Package Delivery Example
Multirotor Aircraft
(m)
<x>
(m)
<y>
(m)
-1
<z>
H
(rad)
<roll>
(rad)
<pitch>
(rad)
<yaw>
UAVState
ClosedLoopModel
UAVState
Animation
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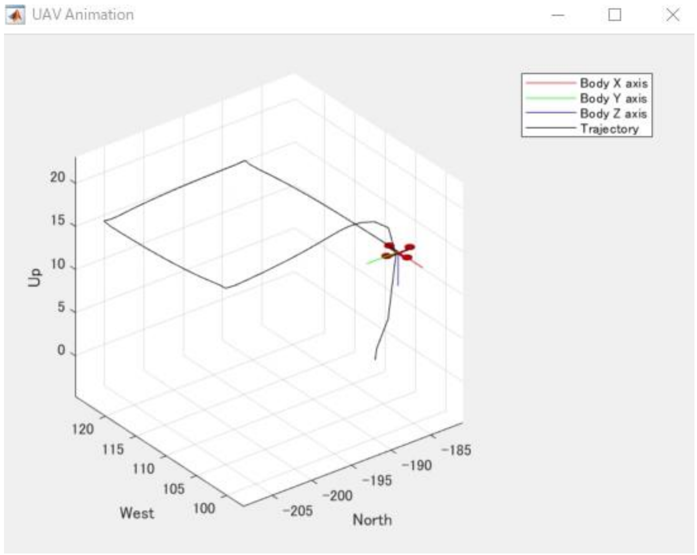
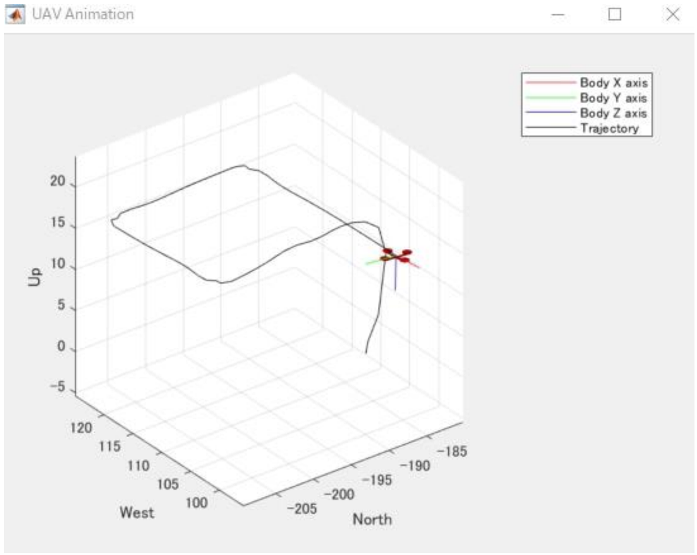
➢ 无风


UAV Animation
Body X axis
Body Y axis
Body Z axis
Trajectory
Up
West
North

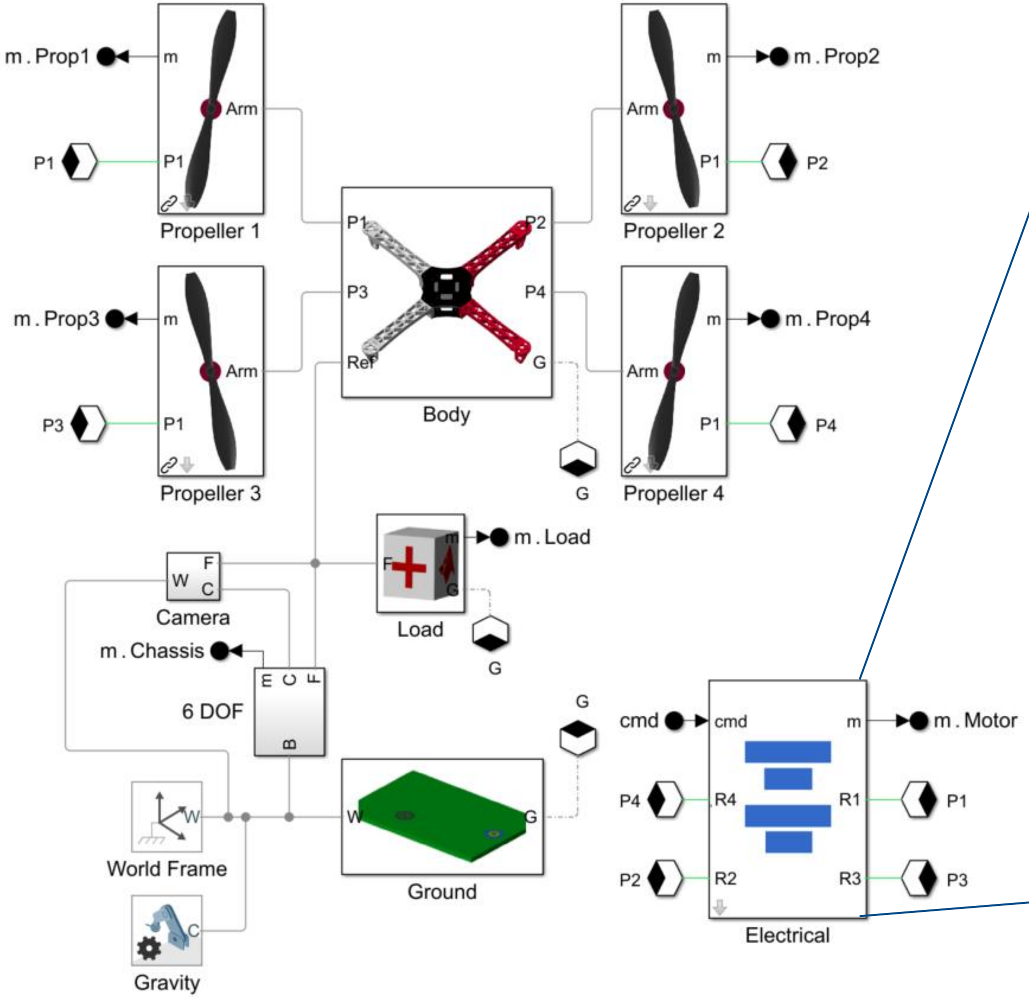
➢ 有风


UAV Animation
Body X axis
Body Y axis
Body Z axis
Trajectory
Up
West
North

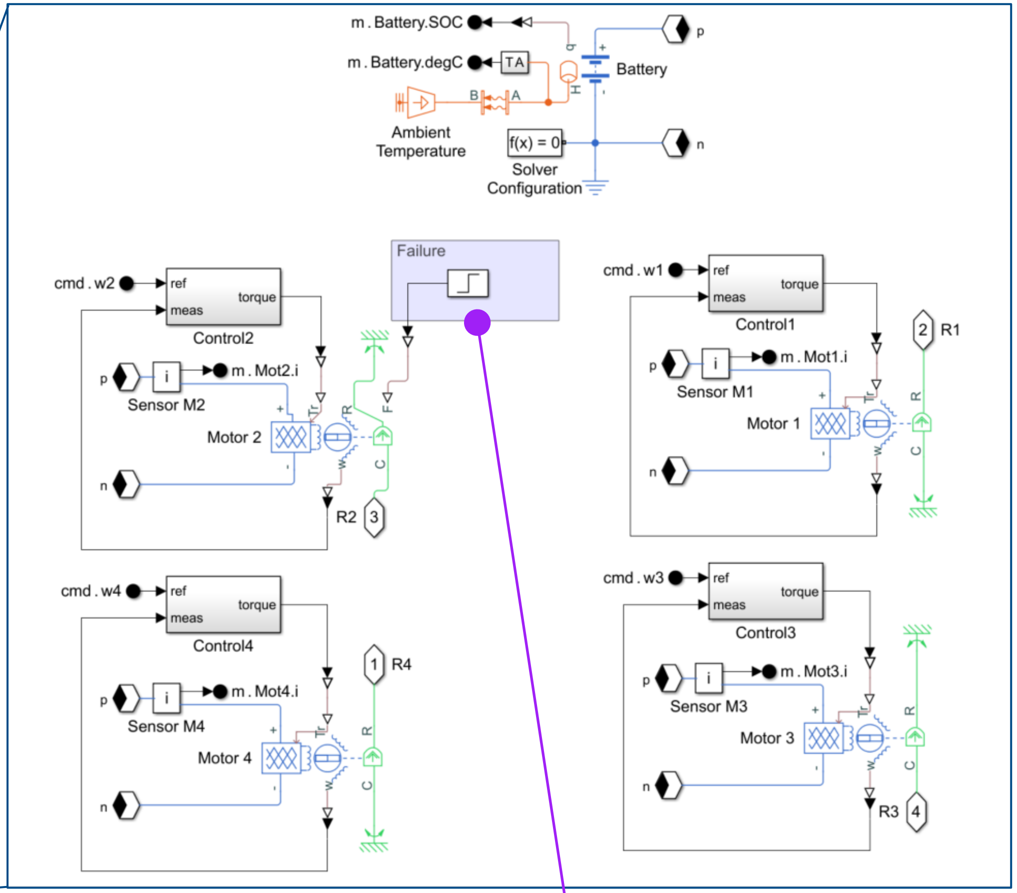
无人机建模示例

Quadcopter Drone Model in Simscape [Link to Model]

刚体运动模型
Simscape Multibody™



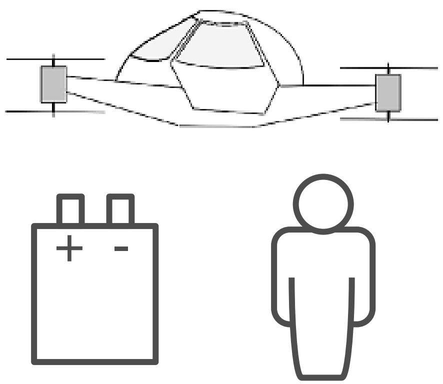
电机和电池
Simscape Electrical™

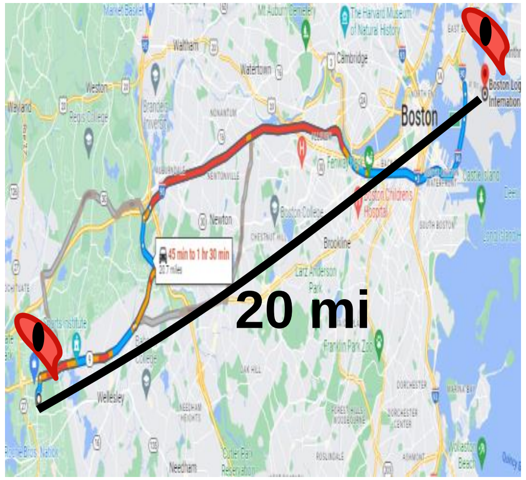


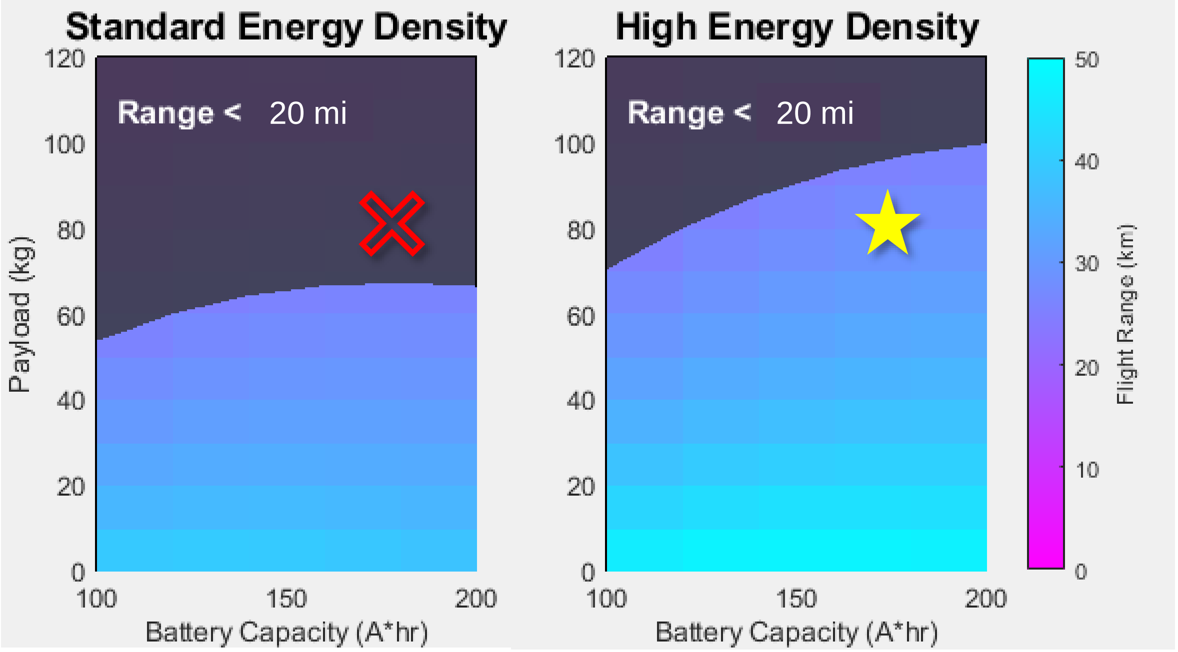
也可以考虑故障的影响

电动飞机设计探索

情况:

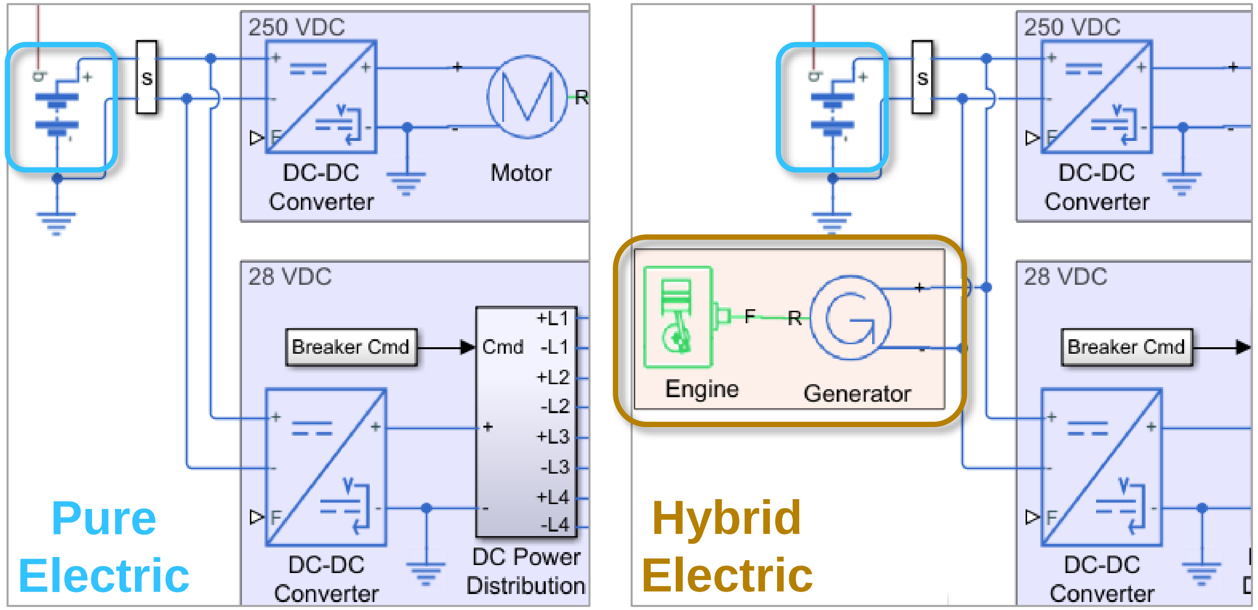




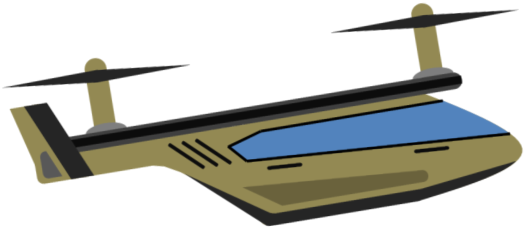


挑战：确定要满足的电池和冷却系统要求，飞行距离和有效载荷要求

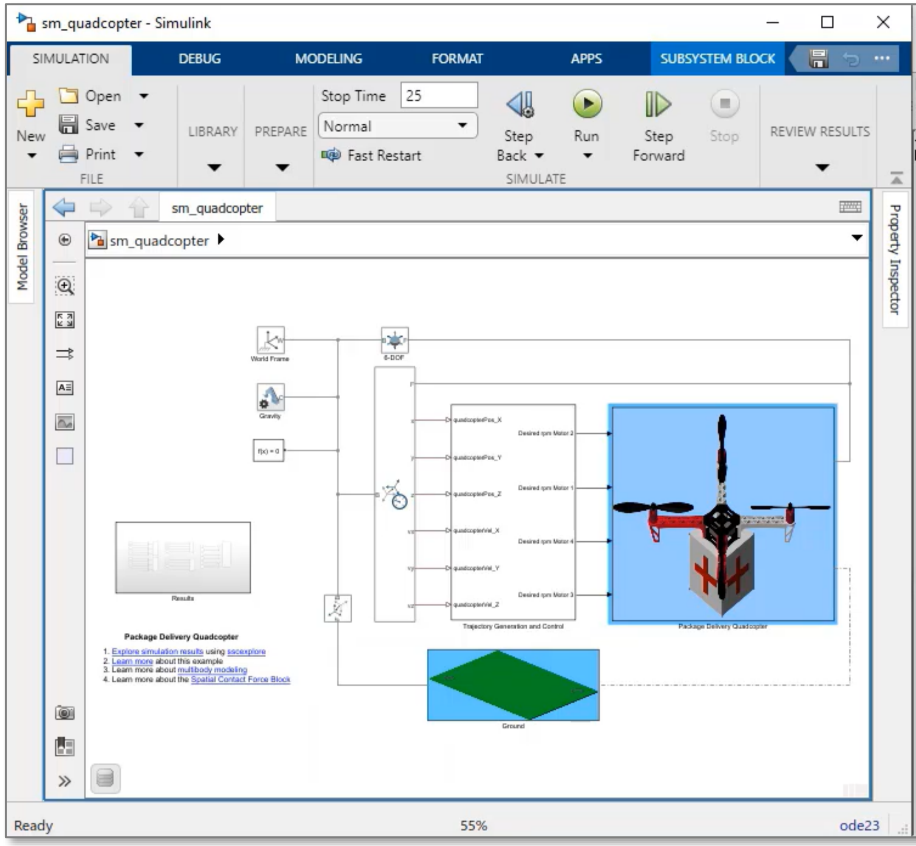
解决方案：使用 Simscape 对系统进行建模，并使用 MATLAB 对每个配置运行参数扫描

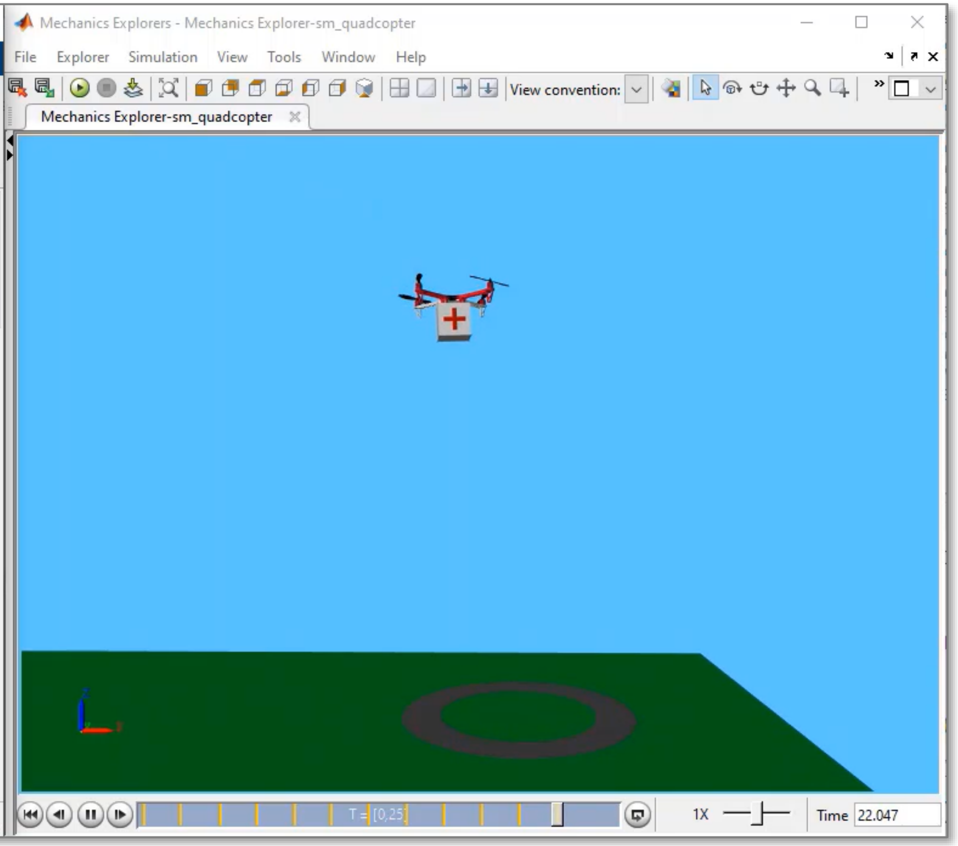


平台设计



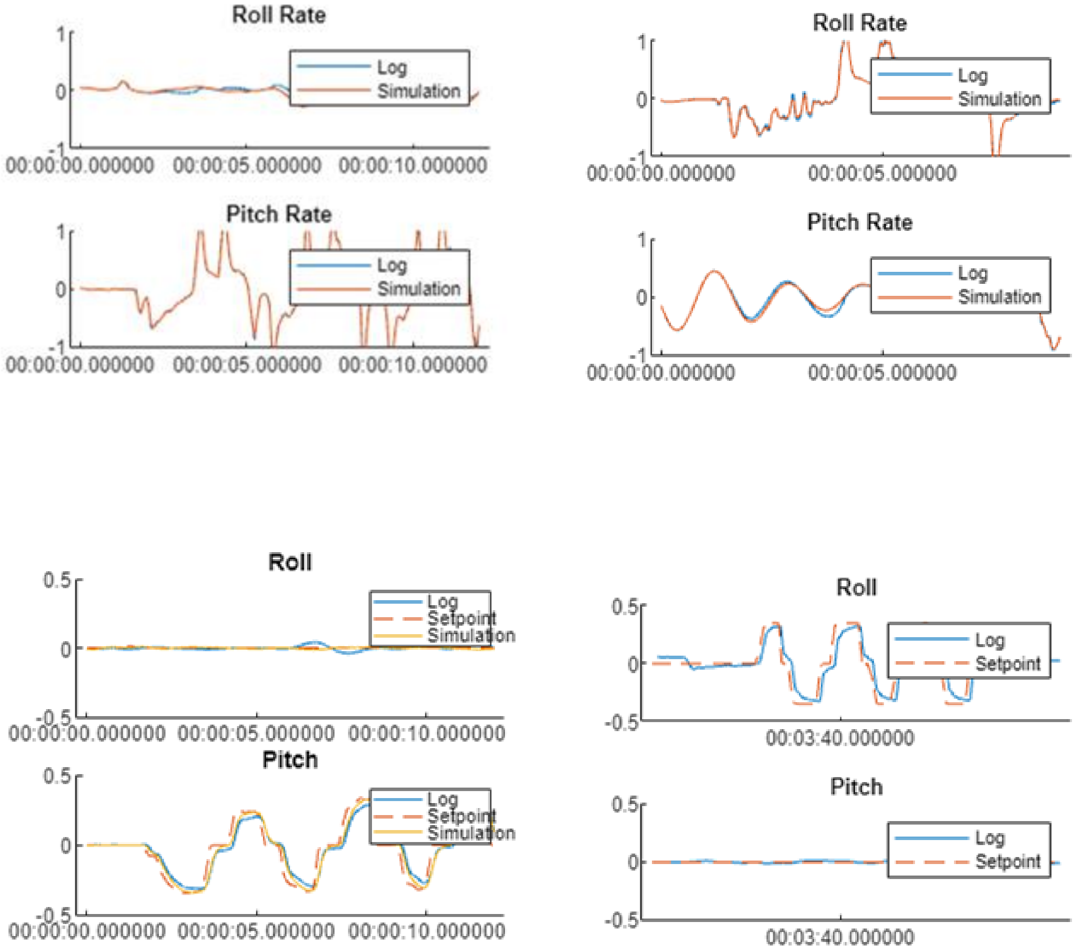
通过建模和仿真进行早期设计分析





被控对象辨识

- 以所需的保真度构建被控对象模型
- 利用现有的 PX4 架构对控制器进行建模
- 估算被控对象参数，如惯性矩阵、推力和阻力系数

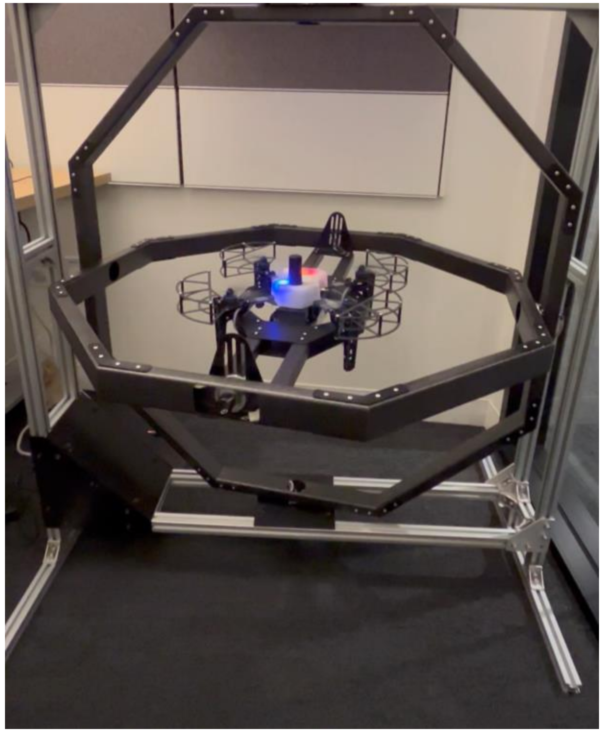


测试设置

Step 1:收集试飞数据

Step 2:导出和处理飞行日志数据

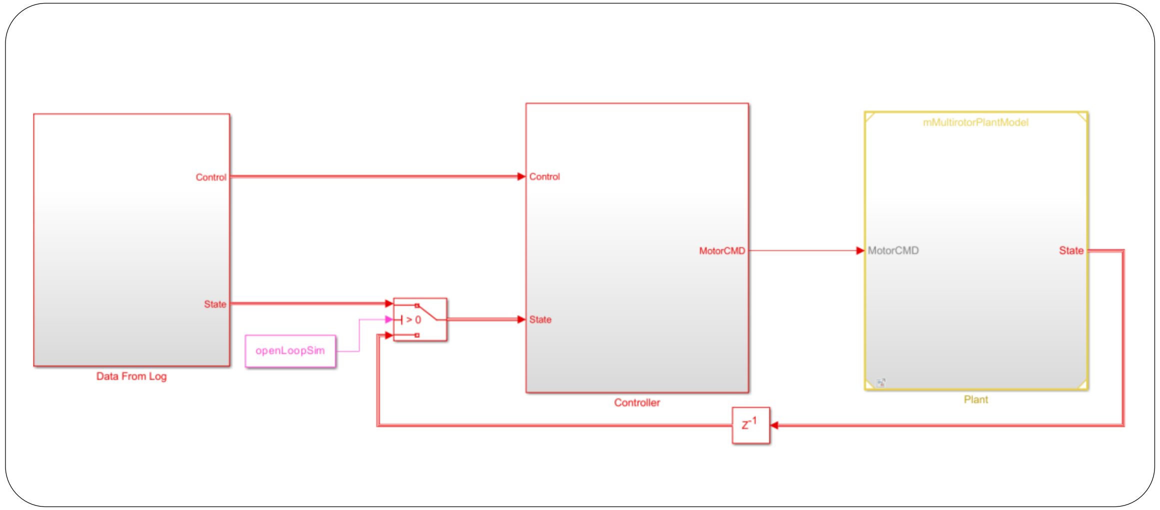
Step 3:验证被控对象模型并调整控制器



UVify IFO-S drone mounted on
Eureka Dynamics FFT GYRO test platform

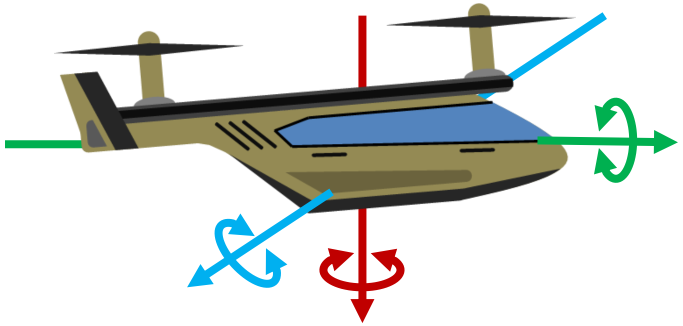
Test Flight

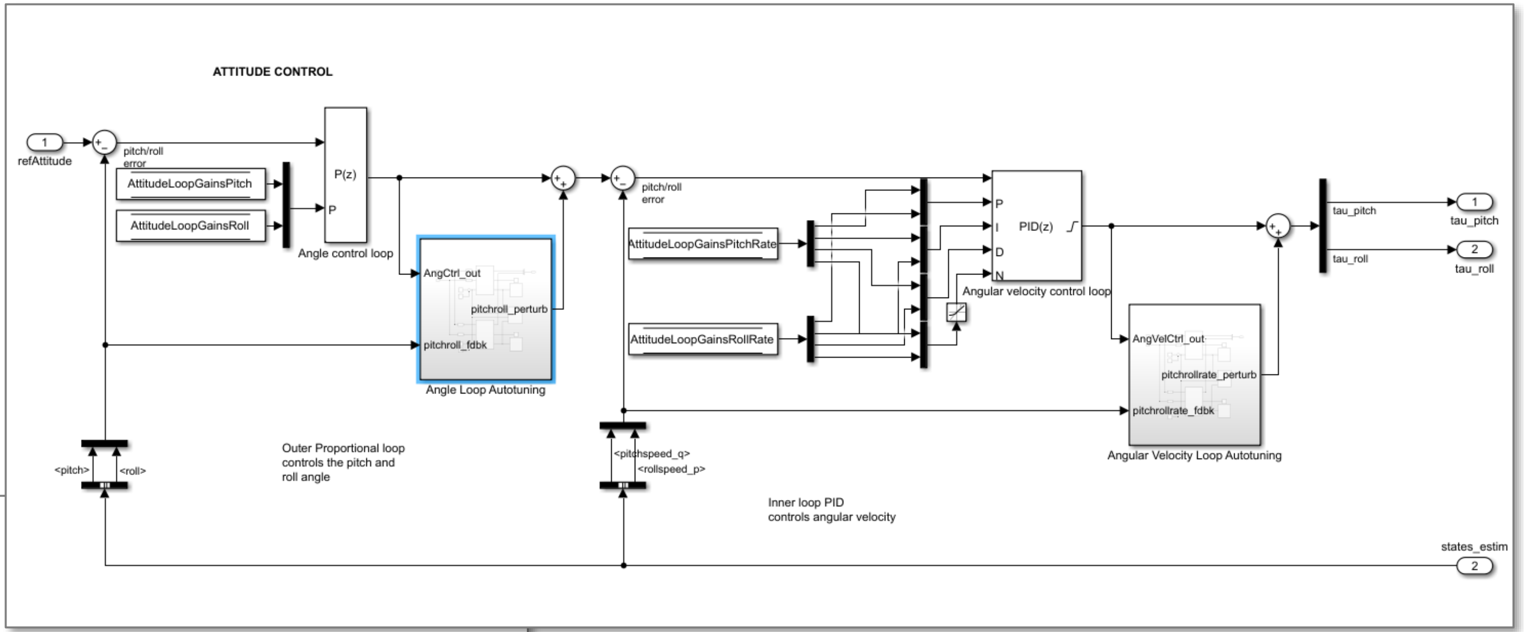
Log Data

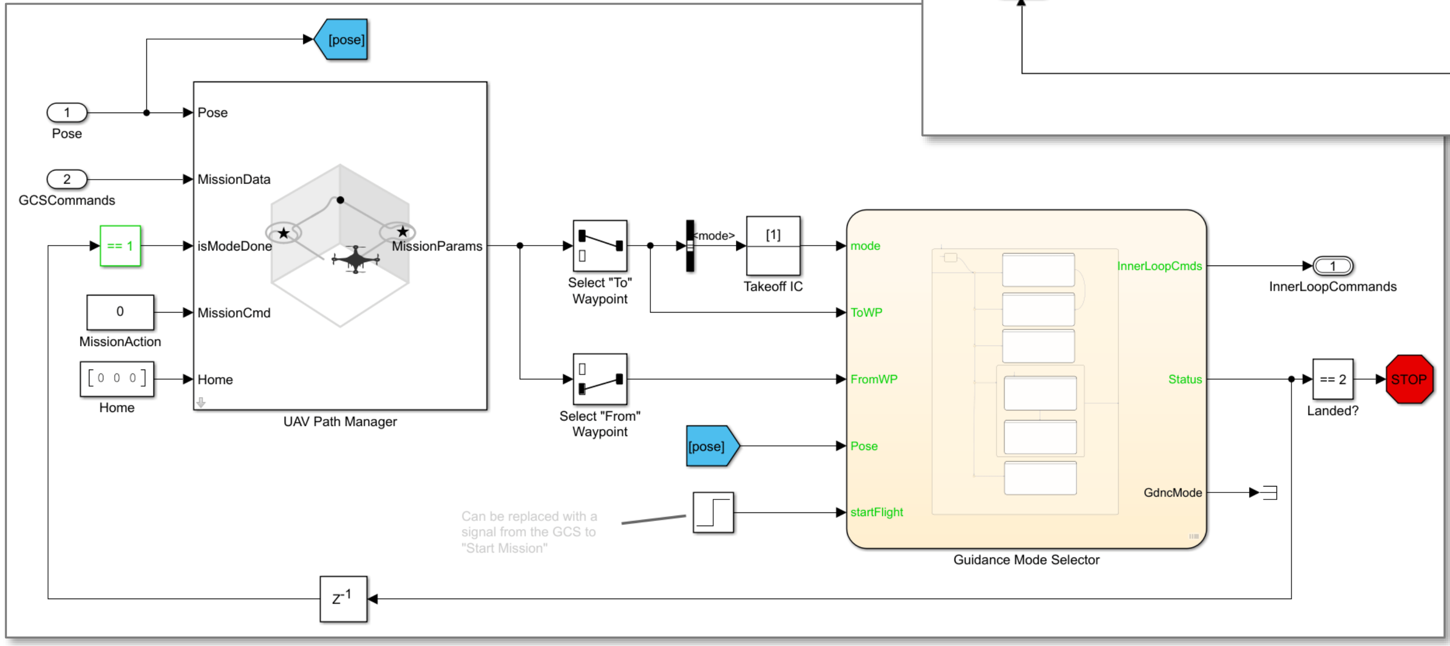


Step 4: Deploy

飞行控制







基于模型设计开发符合航空行业标准的飞控和制导逻辑

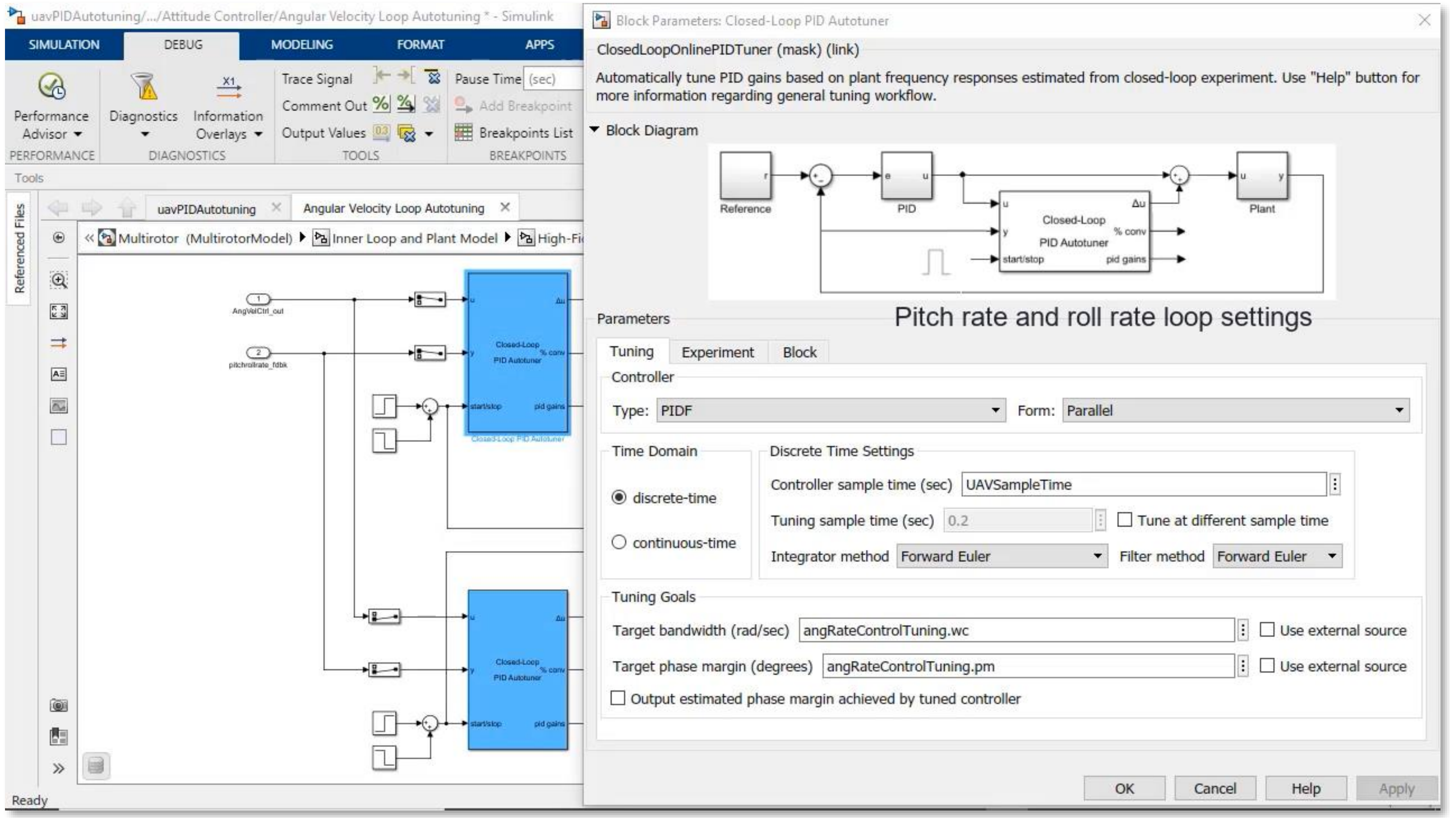
PID控制器的自动调整

控制

Simulink Control Design™

用于位置和姿态控制的自动 PID 调整

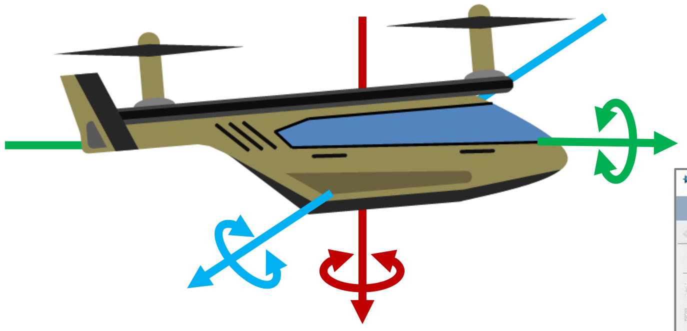
- 指定每个控制回路的性能要求
- Closed PID Autotuner block在仿真过程中自动调整PID控制器



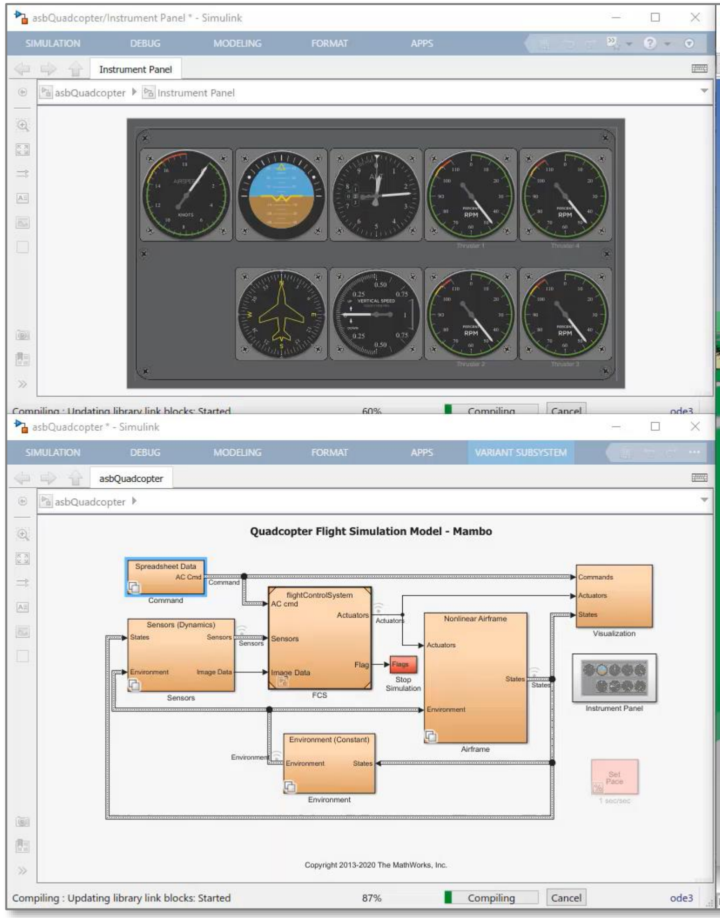
Closed PID Autotuner在线自动调节

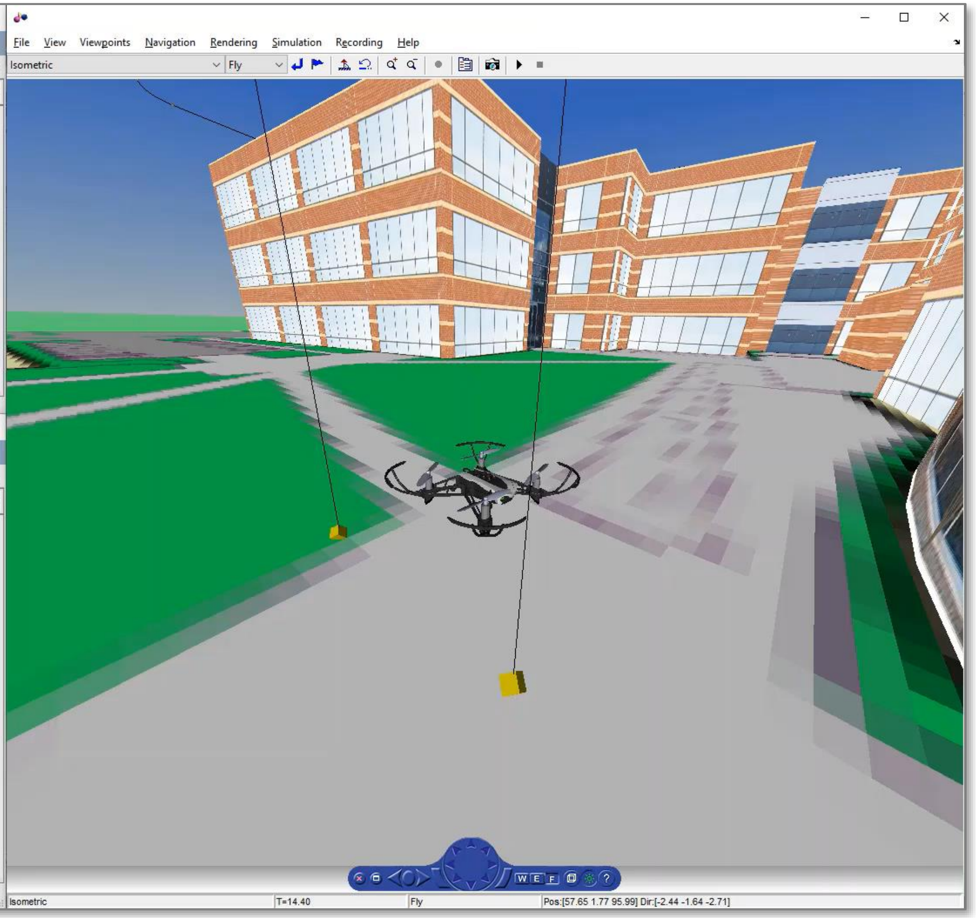
Link

飞行控制

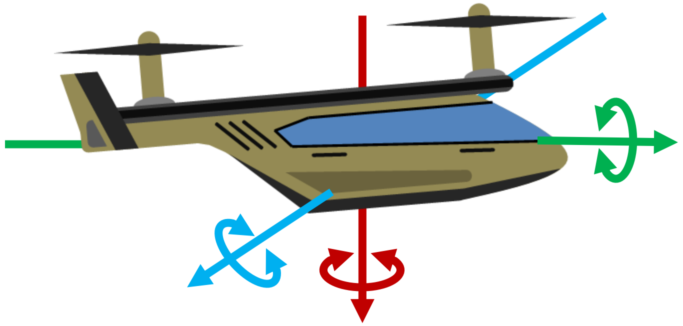


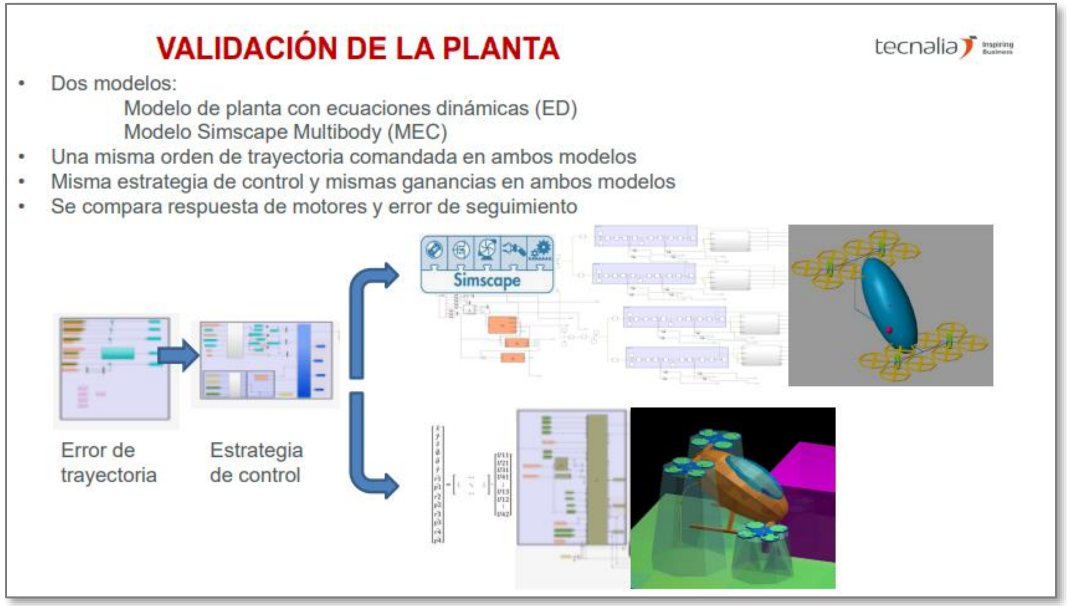
设计以系统级仿真为目标的无人机模型

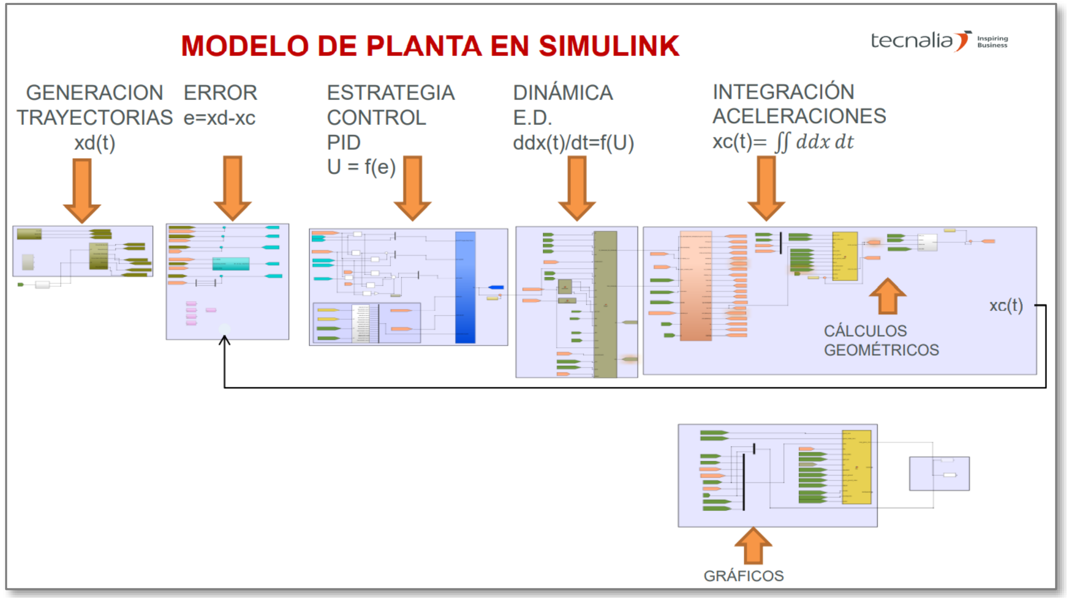




飞行控制



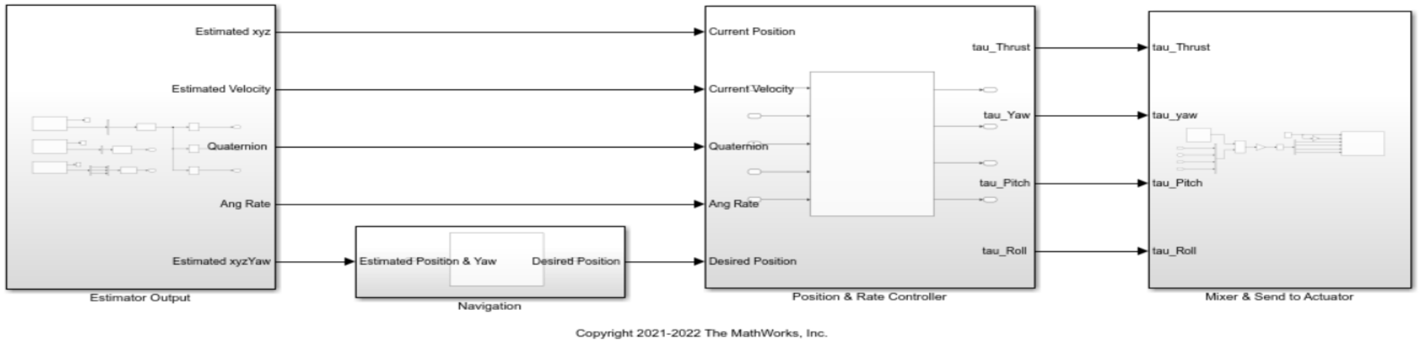




评估特定无人机动力学的飞行控制性能

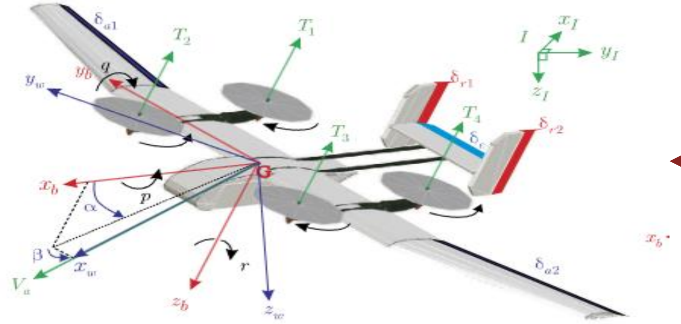
[Link]

VTOL的完整示例

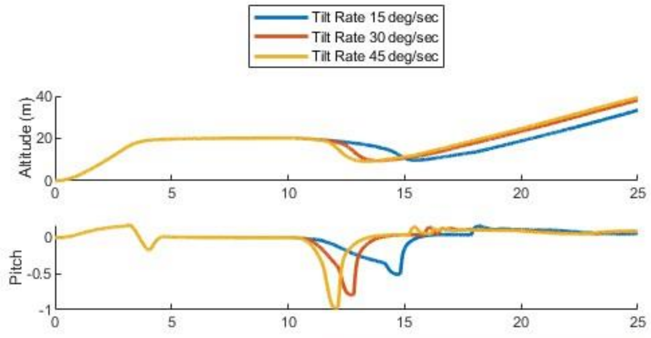


Flight Controller

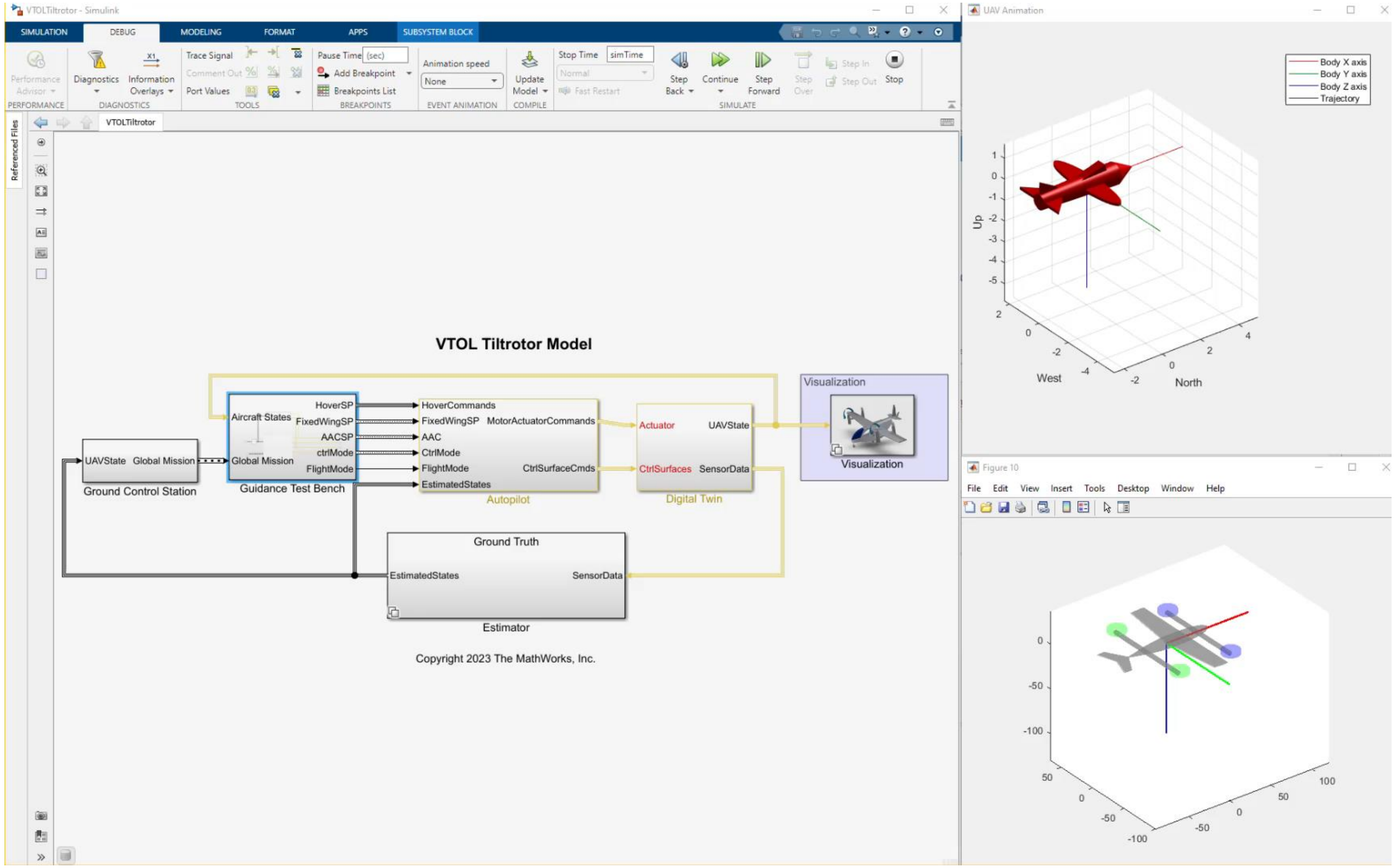
VTOL Plant Model



Simulate Hover,
Transition and Fixed
Wing Guidance Mission.



设计和调整无人机悬停控制

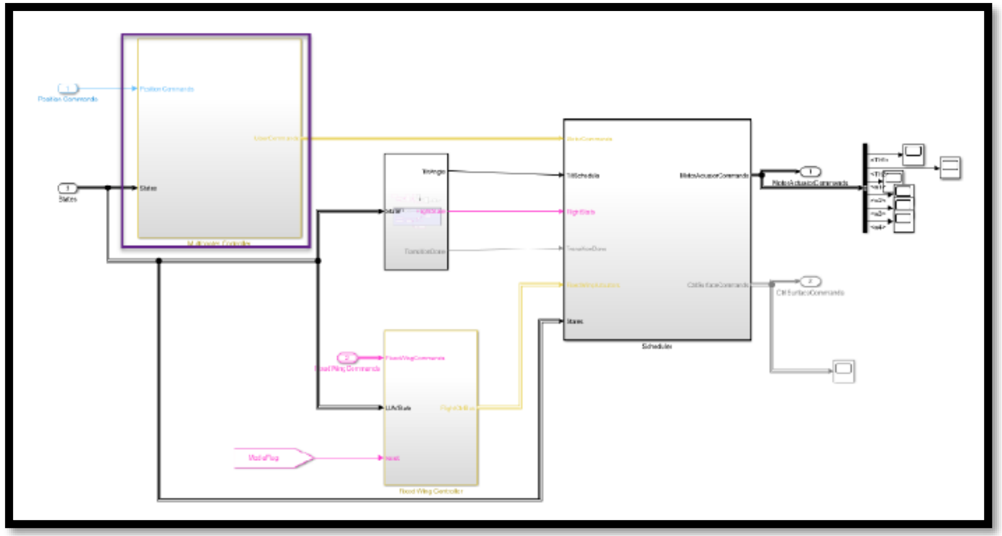


在悬停和固定翼模式下自动调整倾转旋翼机

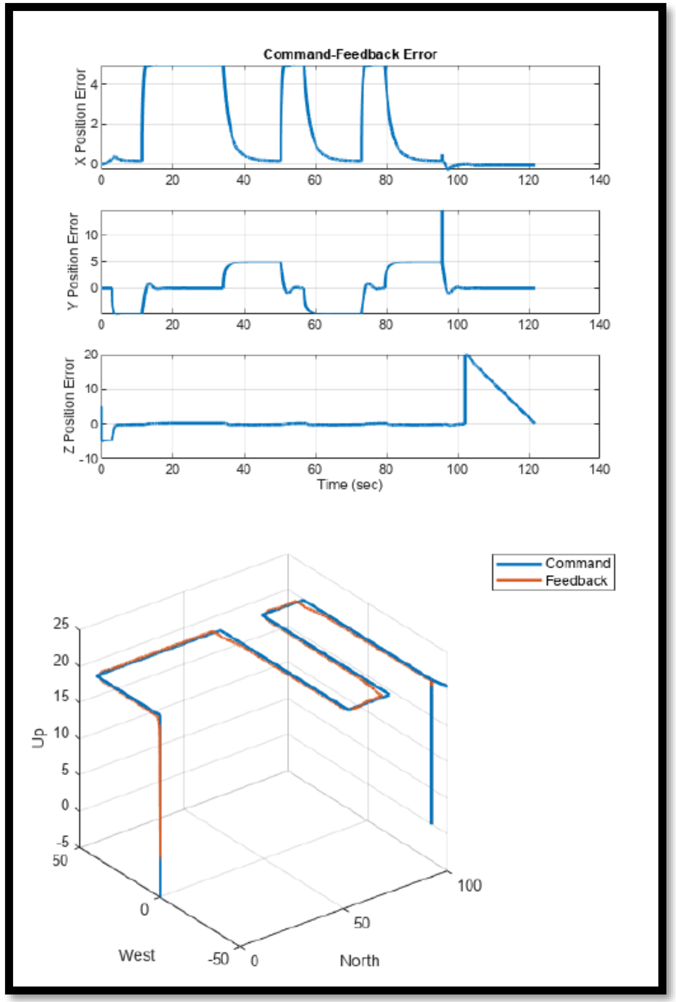
```
%Automate reference tracking optimization for cascaded loop.
automatedHoverControlTuning;
```

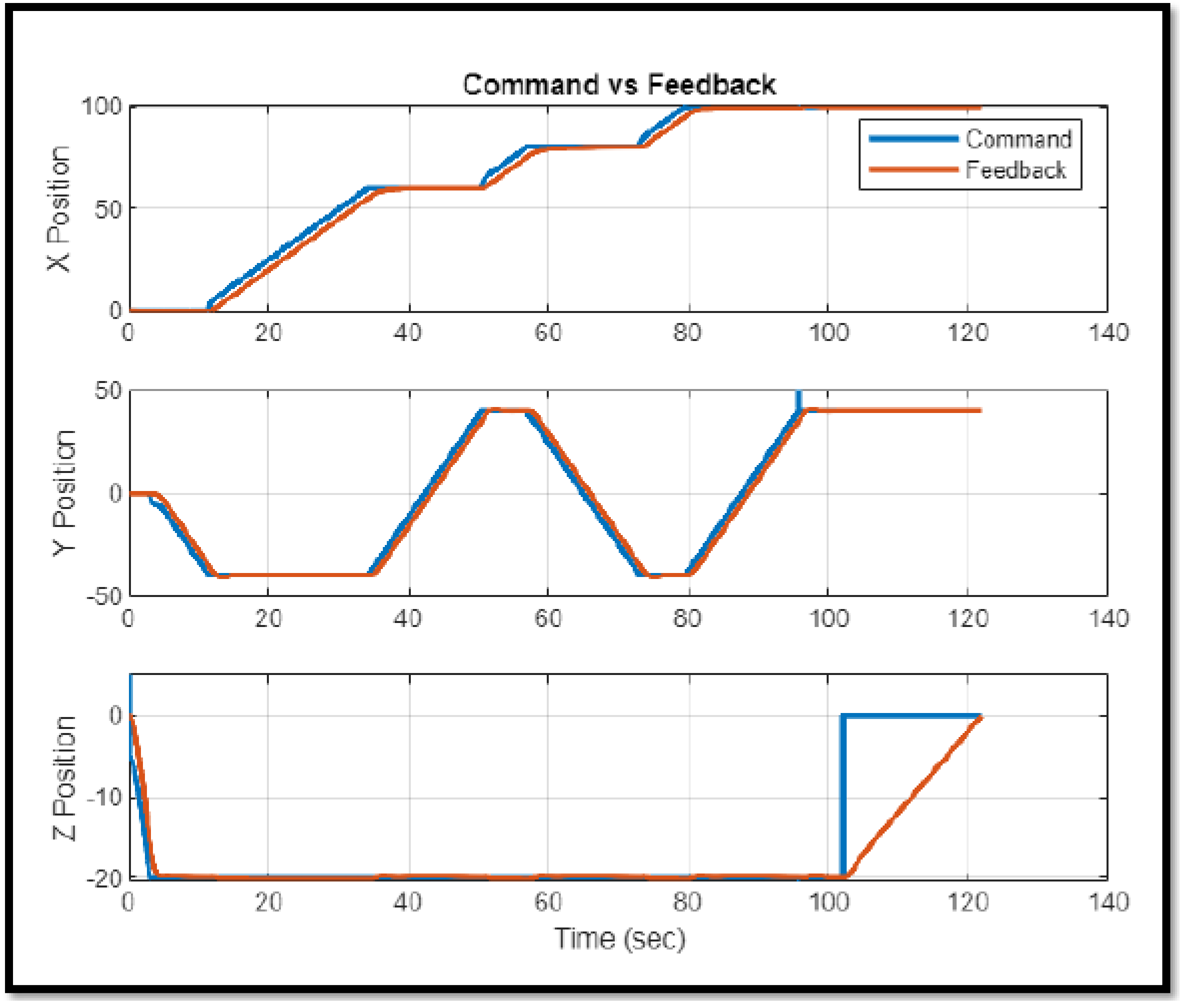
```
%% Roll rate
if TunePrRr
    io(1) = linio([mdl '/Autopilot/Multicopter Controller/Attitude Control/Roll Rate
    io(2) = linio([mdl '/Autopilot/Multicopter Controller/Attitude Control/Demux2'],
    rollRateSys=linearize(mdl,io,options);
    [C,~]=pidtune(rollRateSys,'PDF',50,ctrloptions);
    P_ROLL_RATE=C.Kp;
    D_ROLL_RATE=C.Kd;
    if C.Tf<eps
        C.Tf = 0.01;
    end
    N_ROLL_RATE=1/C.Tf;
end

%% Pitch rate
if TunePrRr
    io(1) = linio([mdl '/Autopilot/Multicopter Controller/Attitude Control/Pitch Rat
    io(2) = linio([mdl '/Autopilot/Multicopter Controller/Attitude Control/Demux2'],
    pitchRateSys=linearize(mdl,io,options);
    [C,~]=pidtune(pitchRateSys,'PDF',50,ctrloptions);
    P_PITCH_RATE=C.Kp;
    D_PITCH_RATE=C.Kd;
    if C.Tf<eps
        C.Tf = 0.01;
```

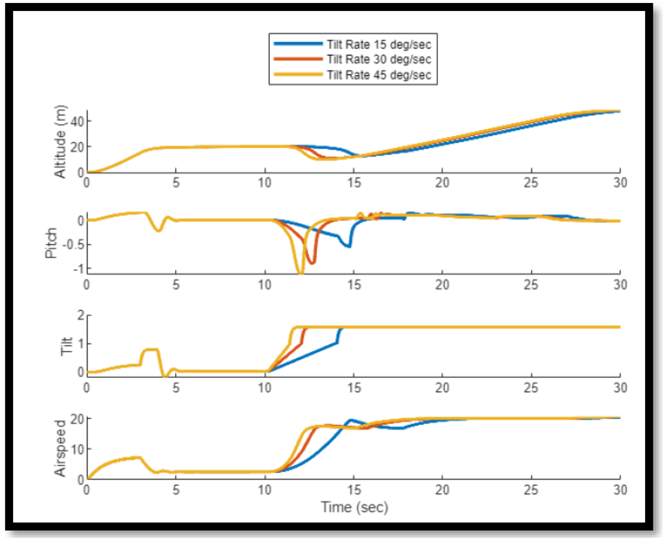


分析跟踪和控制性能

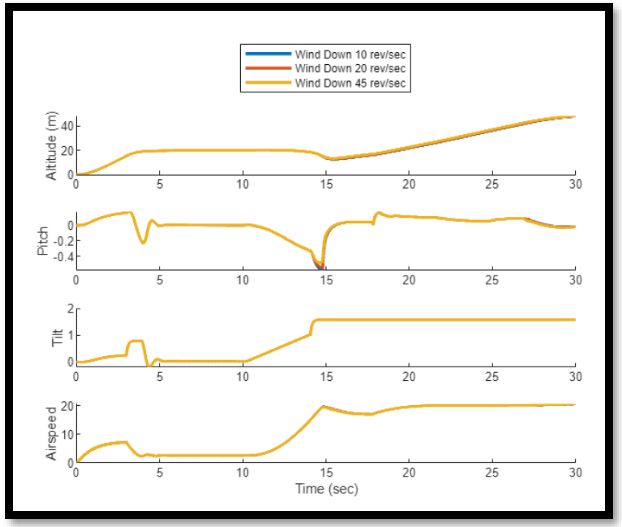

Command-Feedback Error
X Position Error
Y Position Error
Z Position Error
Time (sec)
Command
Feedback
Up
West
North


Command vs Feedback
X Position
Y Position
Z Position
Time (sec)
Command
Feedback

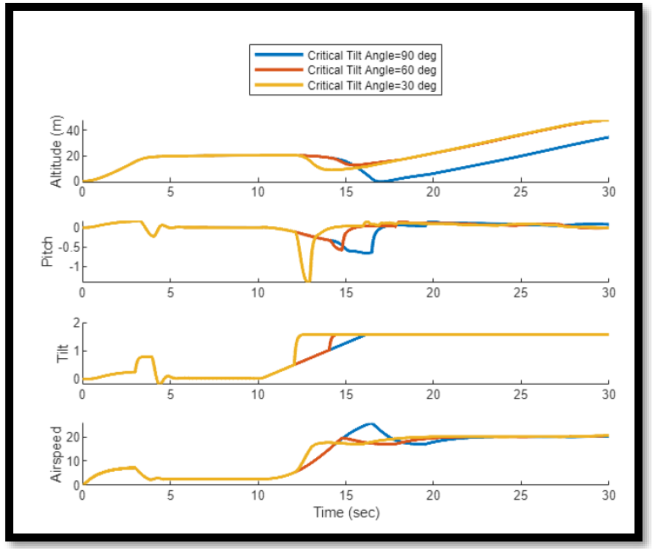
过渡中无人机的调谐控制设计



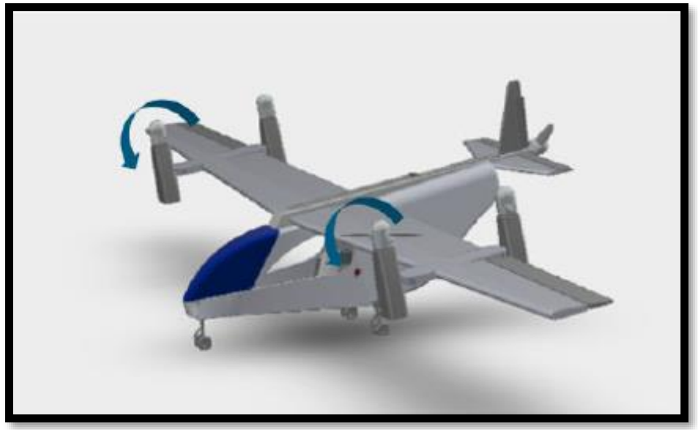
Tilt Rate

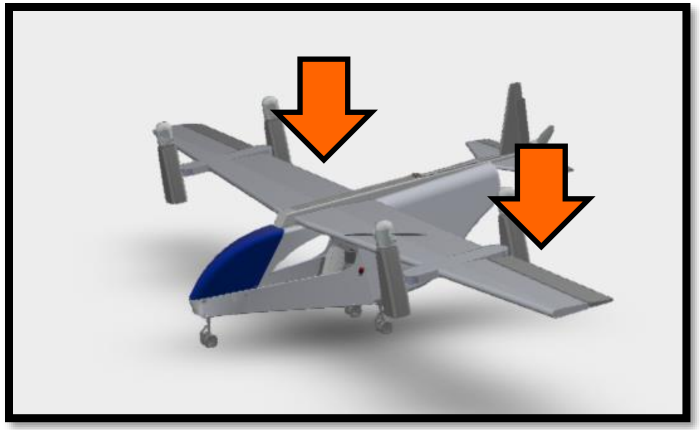


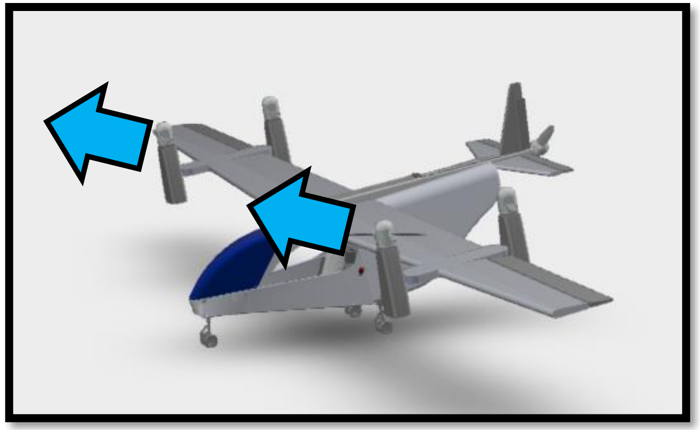
Wind-down rate



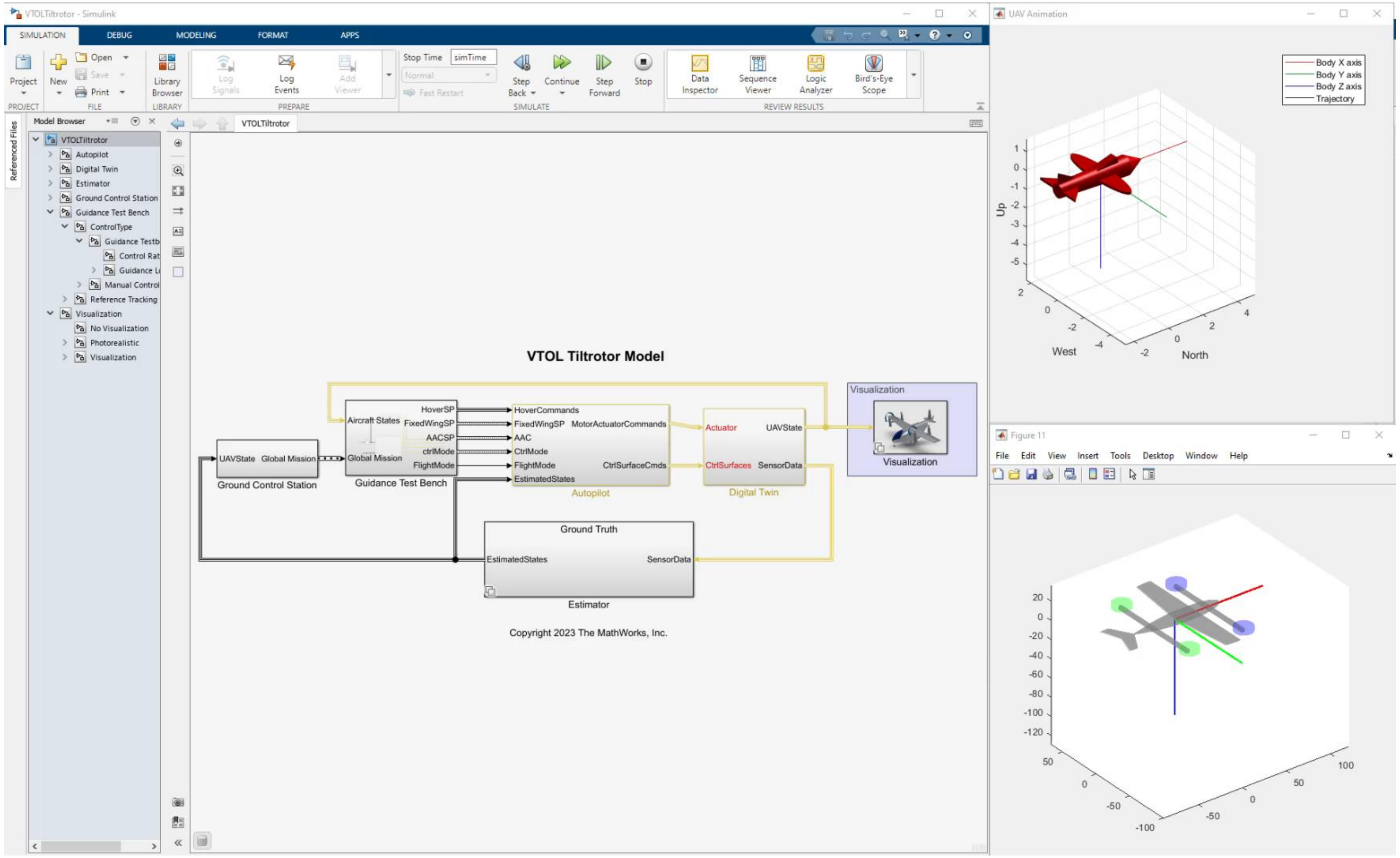
Critical Tilt Angle



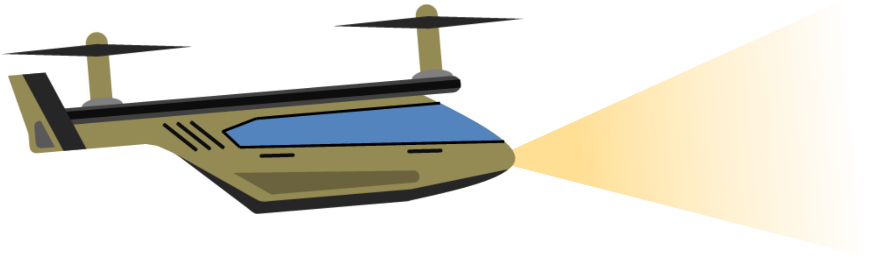




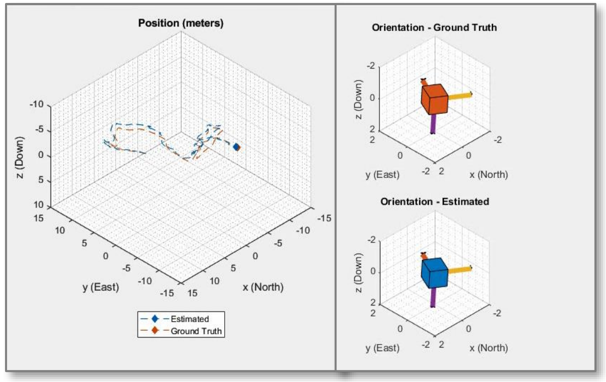
过渡中无人机的调控设计



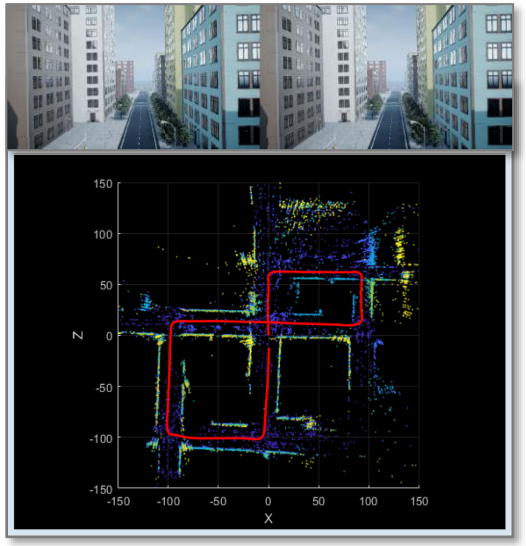
自主飞行 – 感知



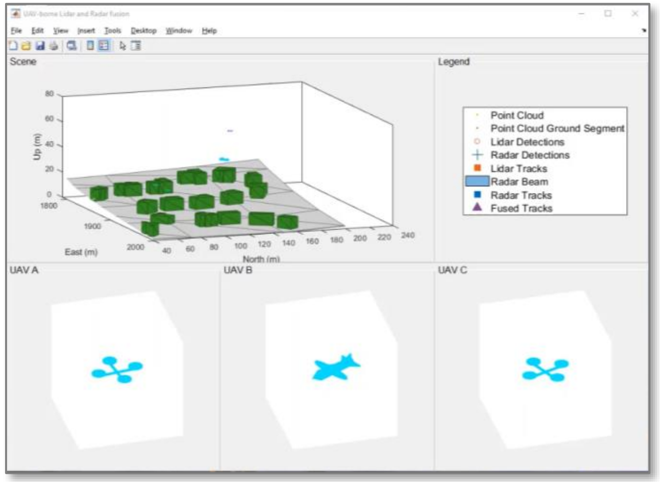
用于设计和评估感知算法的功能



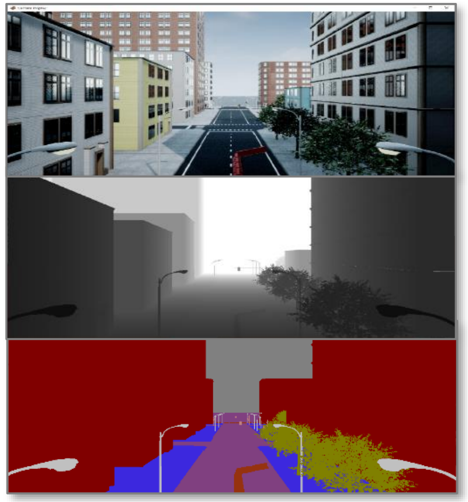
通过传感器融合进行定位



立体视觉 SLAM

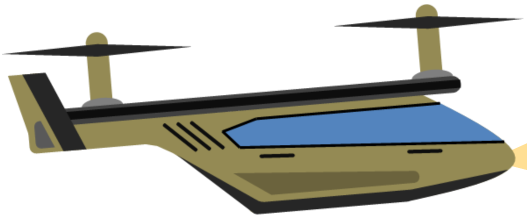


激光雷达和雷达融合，
用于跟踪多架无人机



语义分割

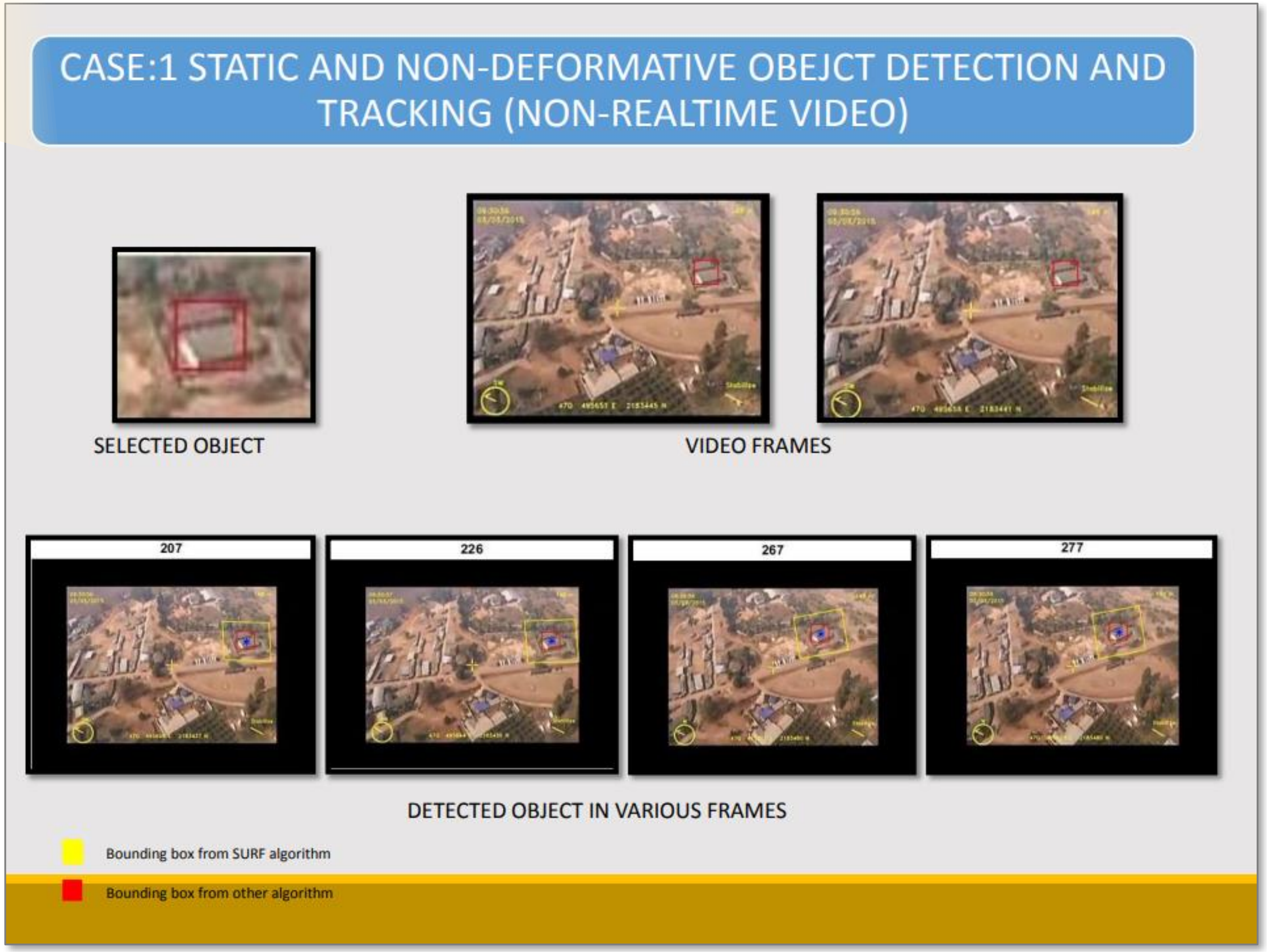
自主飞行 – 感知



Development of Real-Time Object Tracking algorithm for UAVS

DEVSHREE KUMAR,(SCIENTIST,MAV UNIT,NAL,BENGULURU)

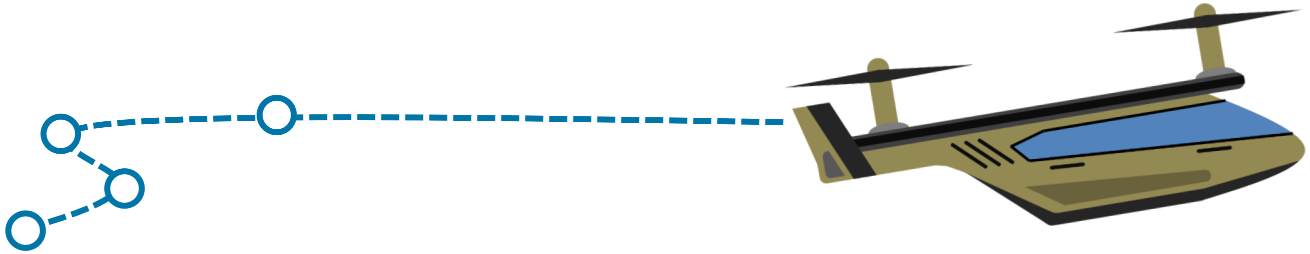
SUVARNA AGARWAL (M.TECH STUDENT)

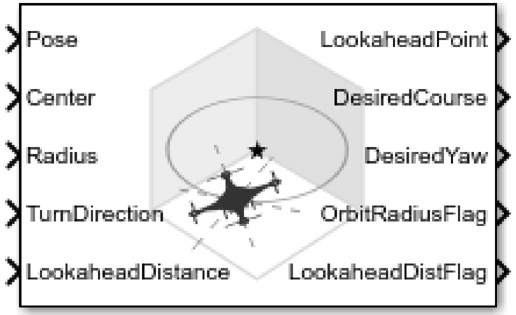


Computer vision capabilities for situational awareness

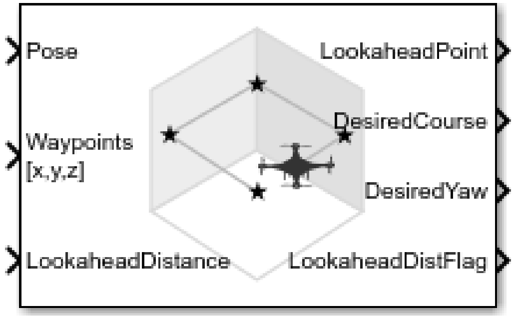
Link

自主飞行 – 运动规划

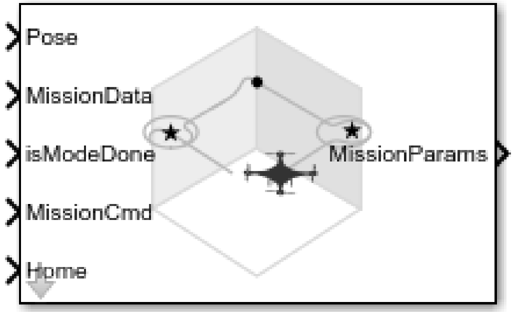




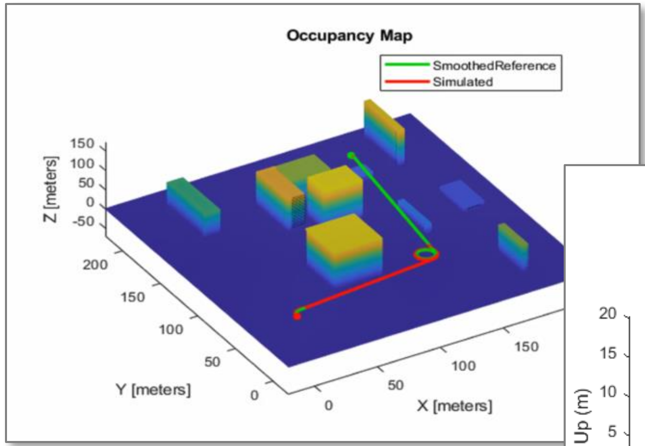
Orbit Follower

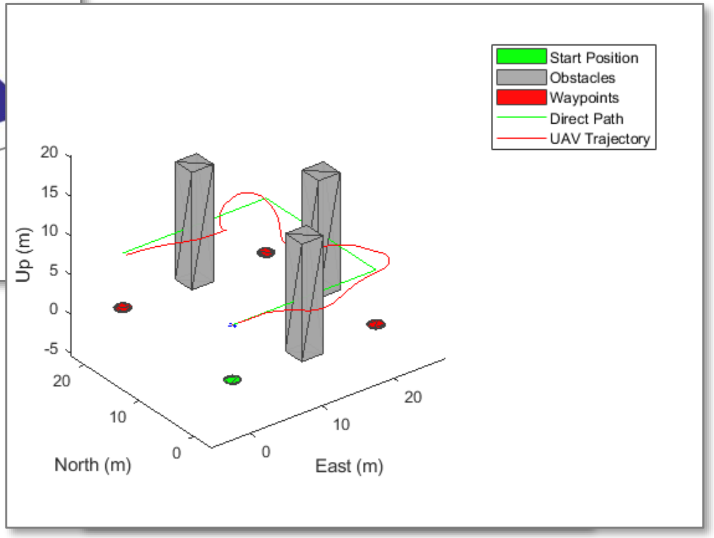


Waypoint Follower



Path Manager

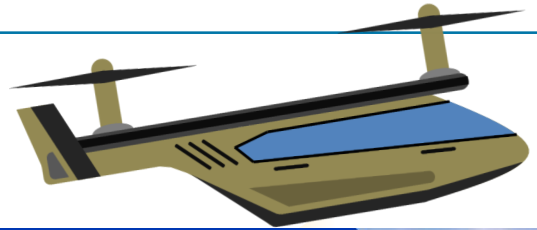


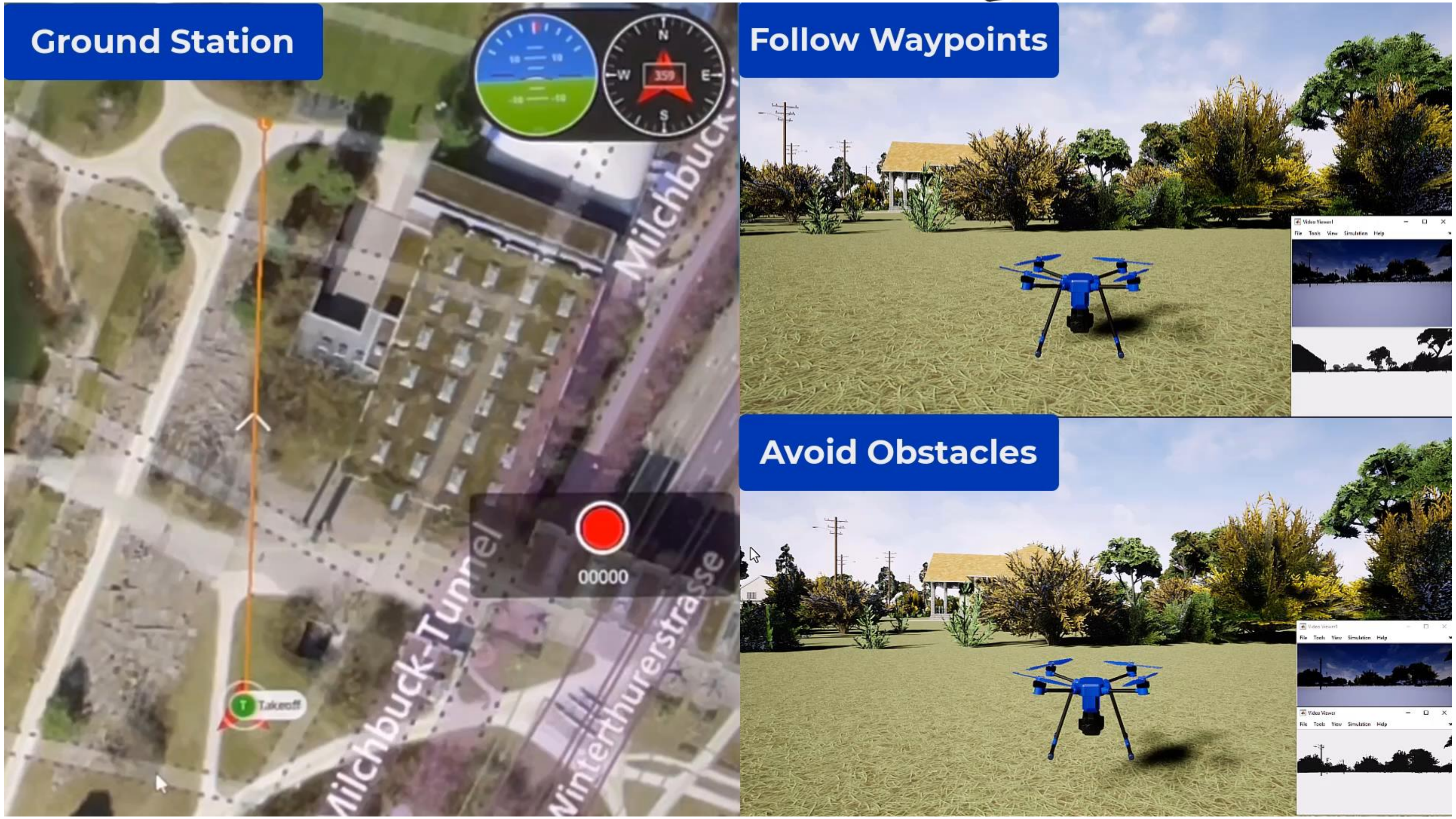


使用航点和轨迹跟踪算法定义任务

使用先进的路径规划器和避障功能进行运动规划

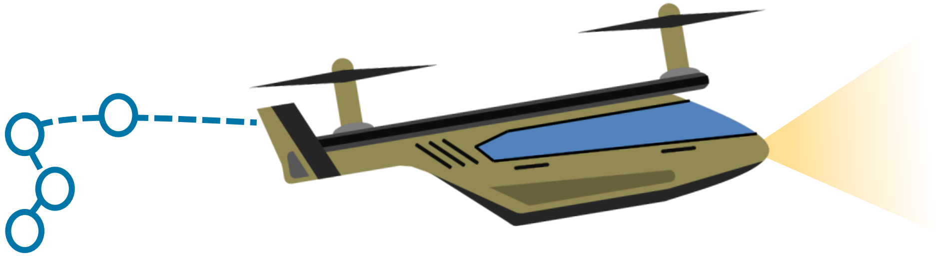
系统级仿真





整合传感器数据反馈，实现系统级闭环仿真

系统级仿真



MILITARY AIR & INFORMATION

BAE SYSTEMS

The Use Of MathWorks Tools in the Unmanned Air Systems Design Process

Alexander McCuish – Flight Control Specialist

6th Nov 2012

Nov 2012 1

BAE SYSTEMS

Examples of Use

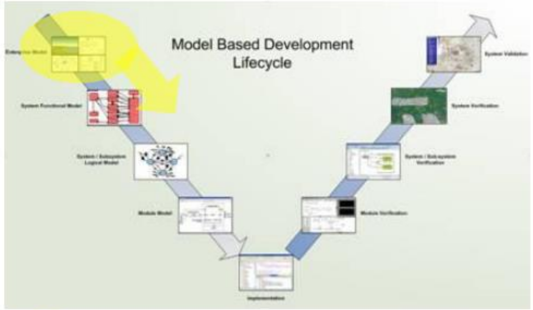
- Electromechanical Actuation Modelling
- Environmental Control System Modelling
- Image Analysis – Object Detection and Recognition
- Flight Data Plotting
- Air Vehicle Concept Analysis

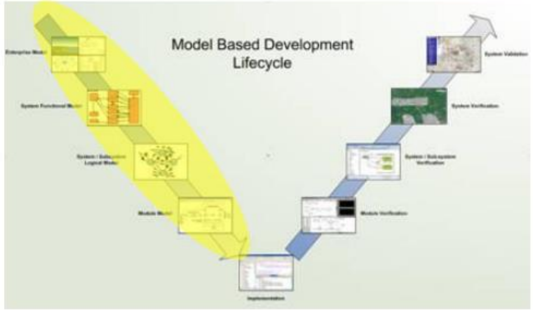
BAE SYSTEMS

MATLAB / Simulink - Pattern of Adoption

Generally the adoption of MathWorks' products follows a similar pattern;

- Initial use to support current process and tools e.g. data transfer, data visualisation.
- Spreads to use in early stages of lifecycle to rapidly assess various options.
- Use extends across the lifecycle as confidence and capability grows.
- Aided by
  - Need to maintain commonality with other disciplines.
  - Pool of recent graduates more familiar with MATLAB/Simulink than Fortran.
- Resisted by
  - Inertia of legacy (qualified) toolsets.
  - Investment to make the change,
  - Appropriate time to make the change.



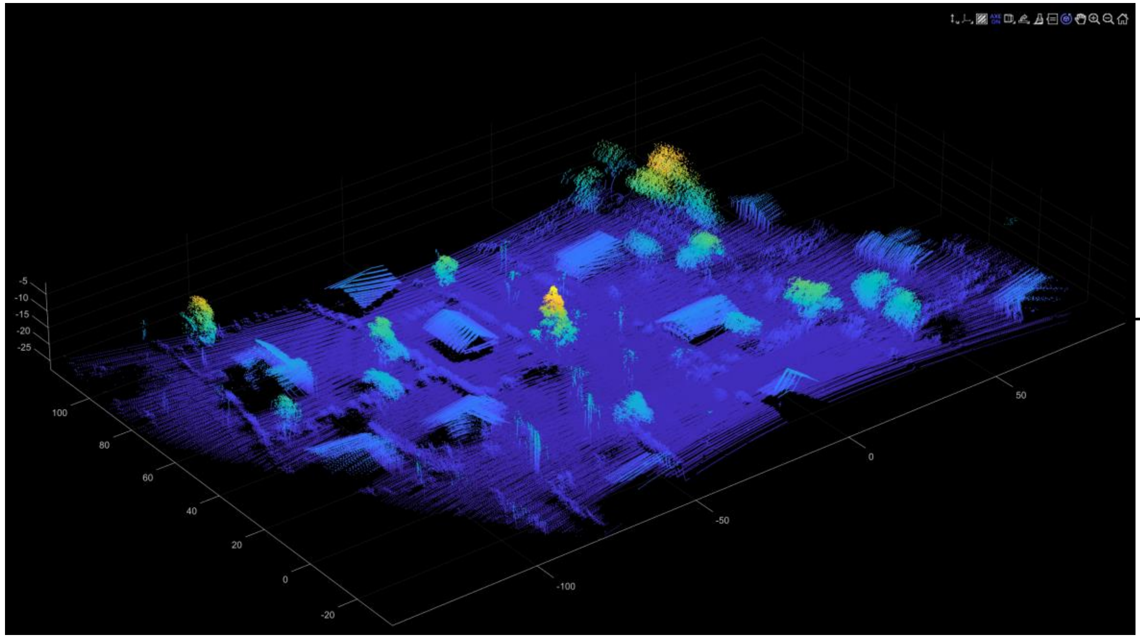


Nov 2012 10

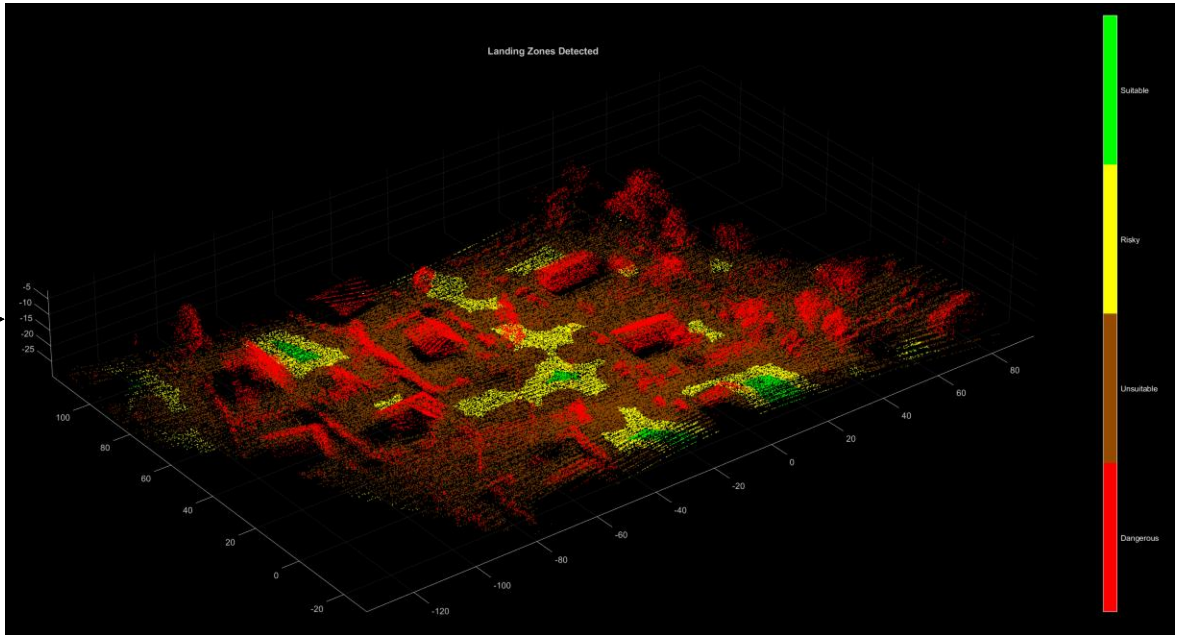
结合无人机、自主算法和环境来模拟必要的测试用例

紧急着陆程序的示例

安全着陆区检测



Input: Point Cloud Map



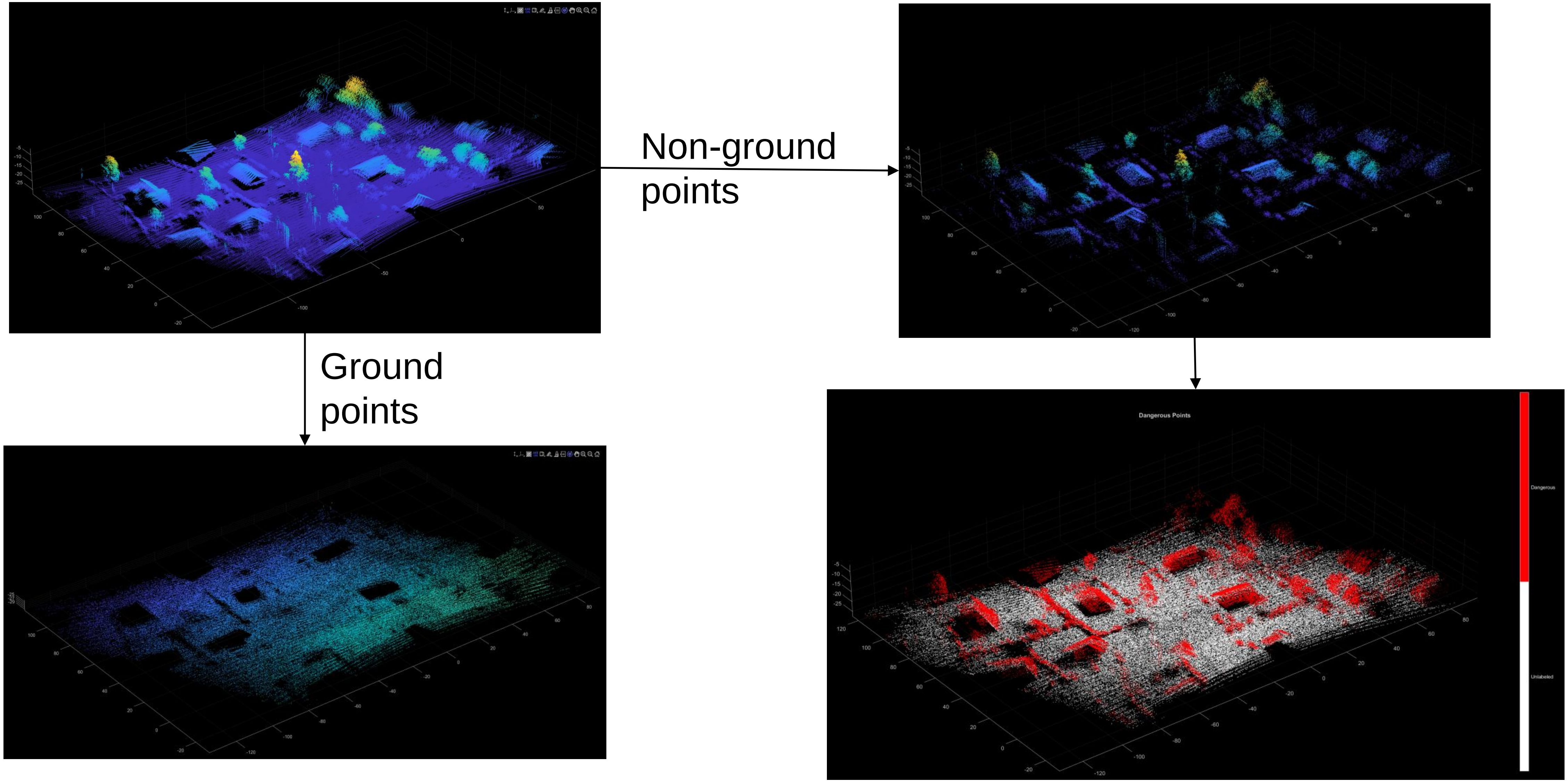
Output: Labelled Landing Zone Points

Point Type	Dangerous	Unsuitable	Risky	Suitable
Color				

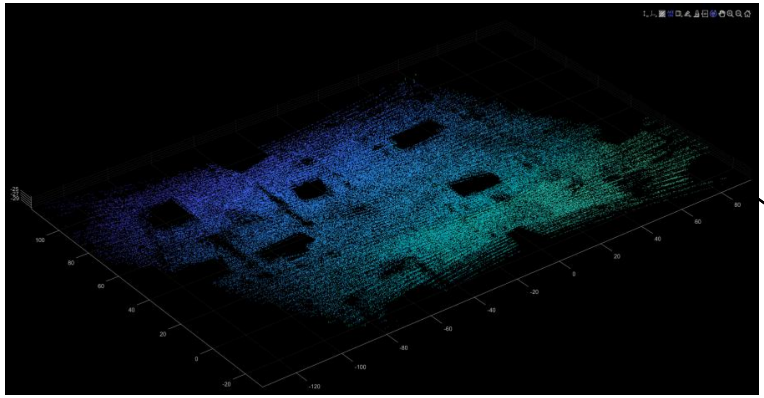
Link to the example :
Determine Safe Landing Area for Aerial Vehicles Example

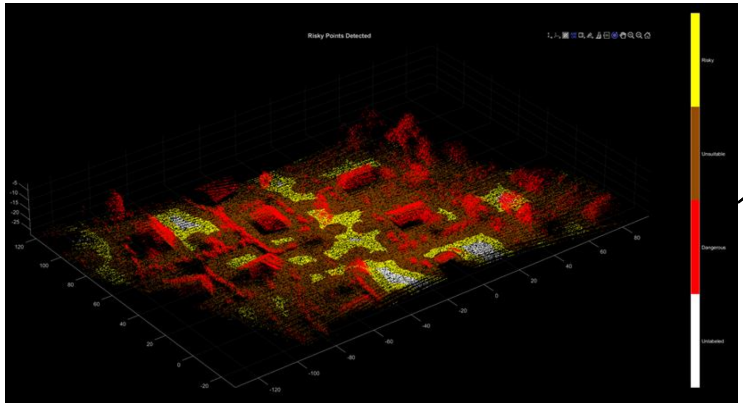
紧急着陆程序的示例

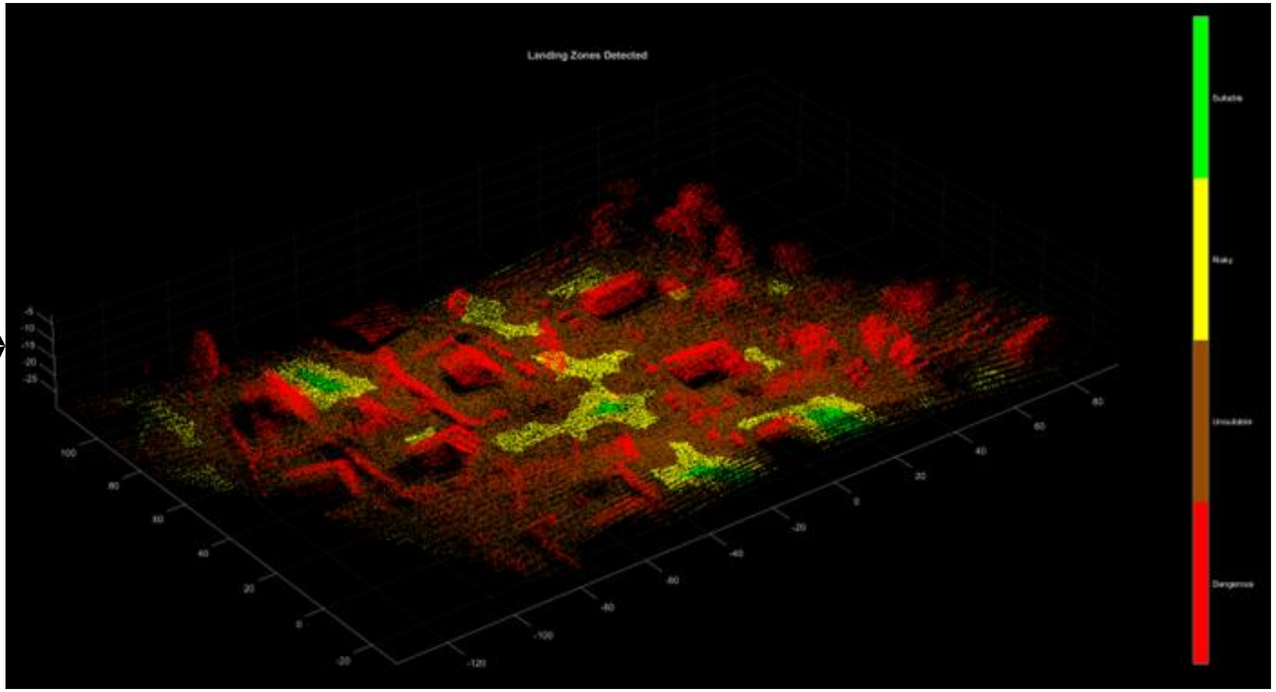
识别危险区域



确定合适的着陆点




Risky Points Detected
Risky
Unsuitable
Dangerous
Unlabeled


Landing Zones Detected

最佳登陆区域位置工作流

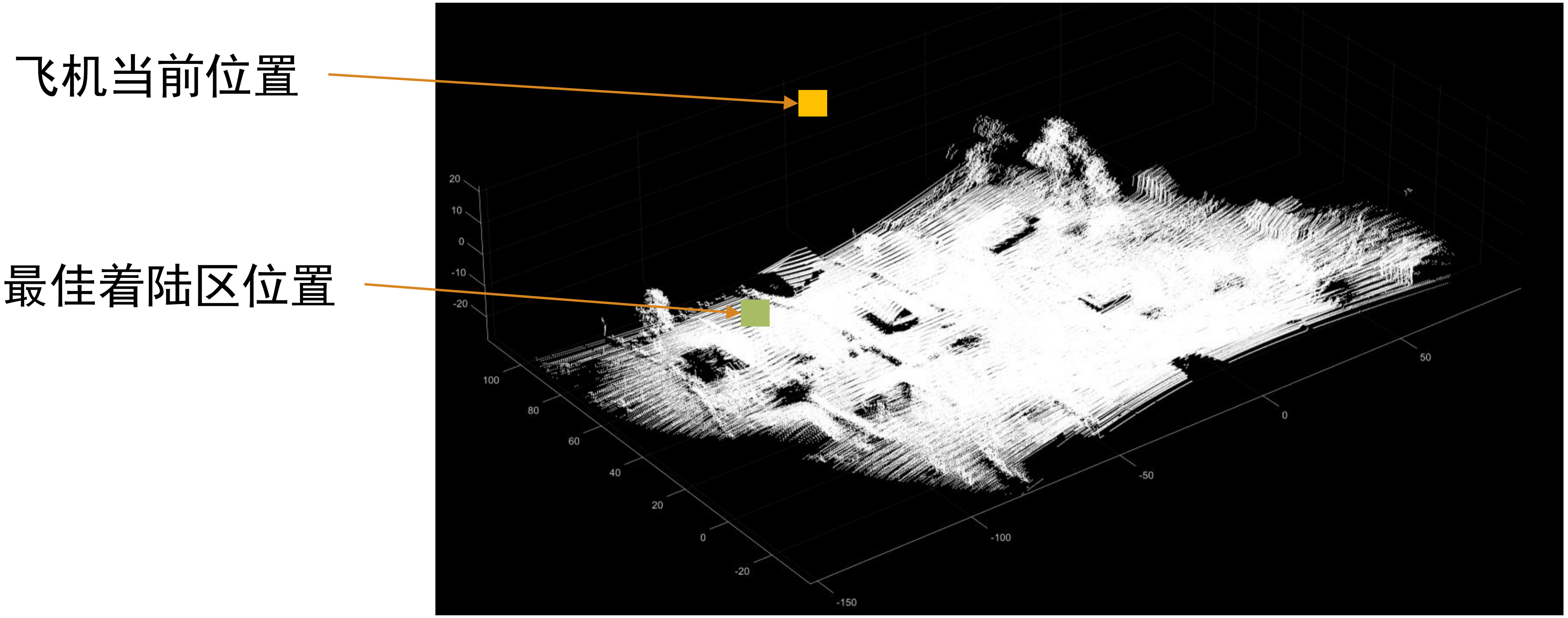
0.7	0.8	UAV		0.4
		0.6	0.6	0.3
		0.7	0.1	0.2

Filter points with high weighted average →

		UAV		
				0.3
			0.1	0.2

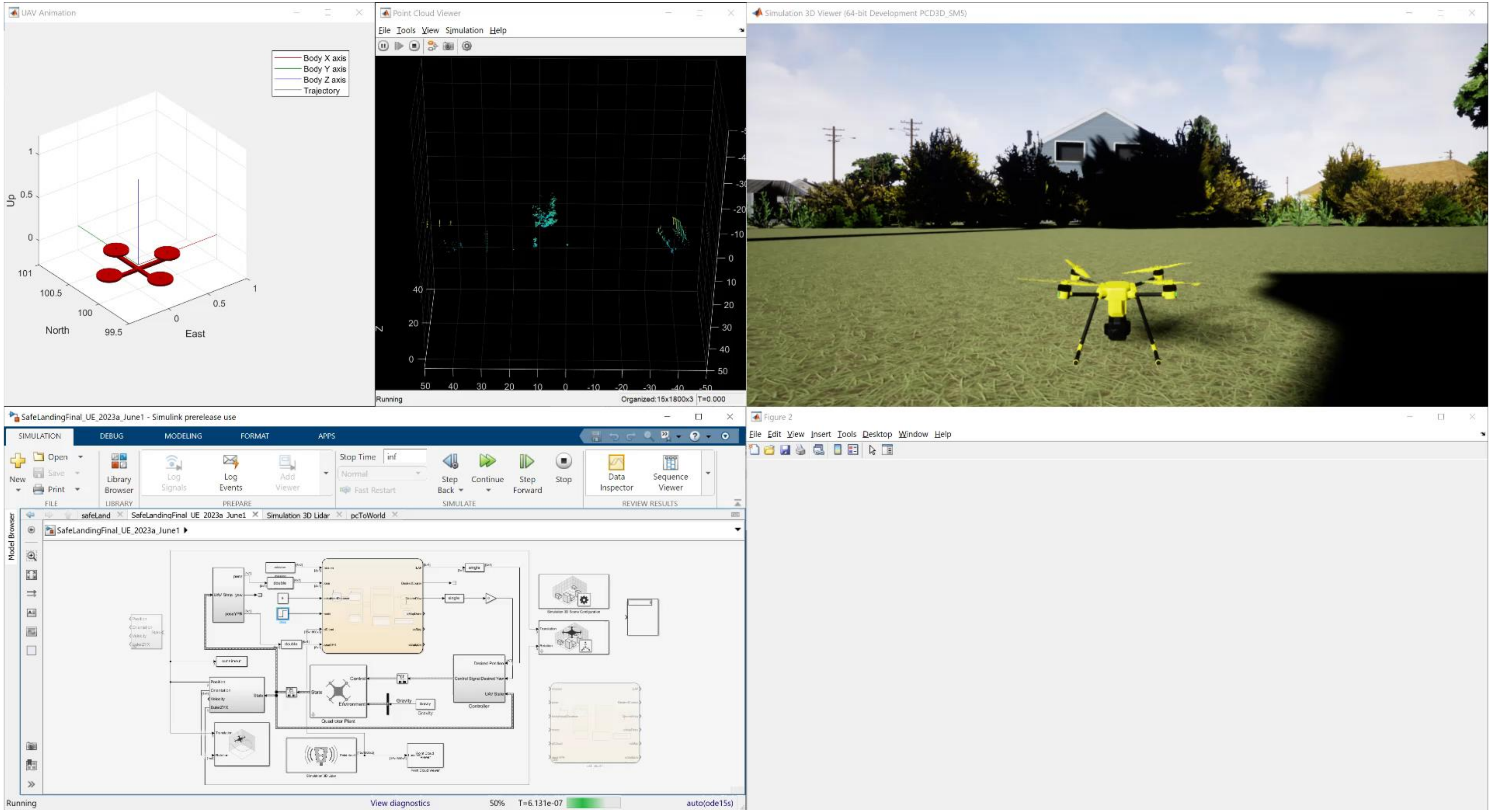
Safest and Closest point from UAV Location →

		UAV		
			0.1	

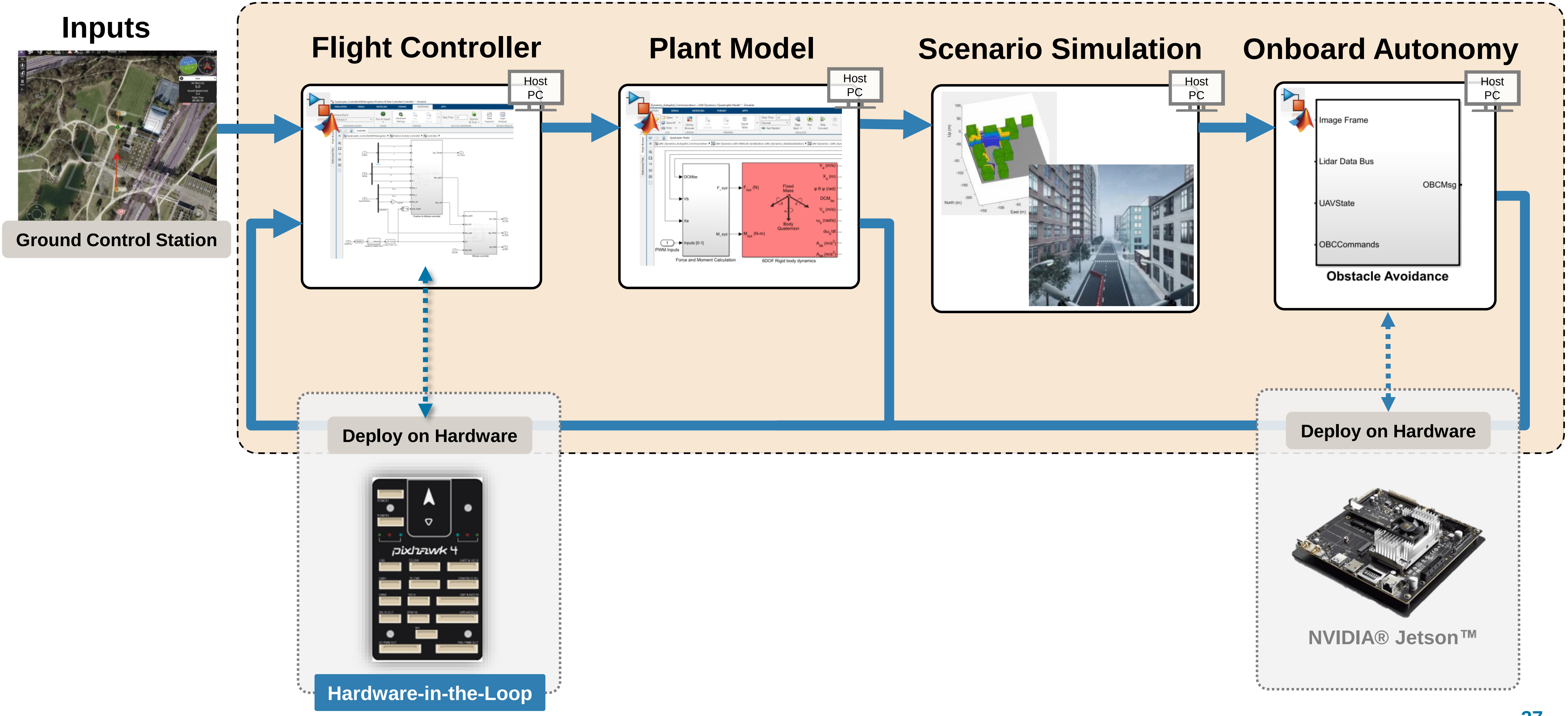


Color	Point Type
	Current UAV Location
	Dangerous
	Unsuitable
	Risky
	Suitable
	Best Landing Zone Location

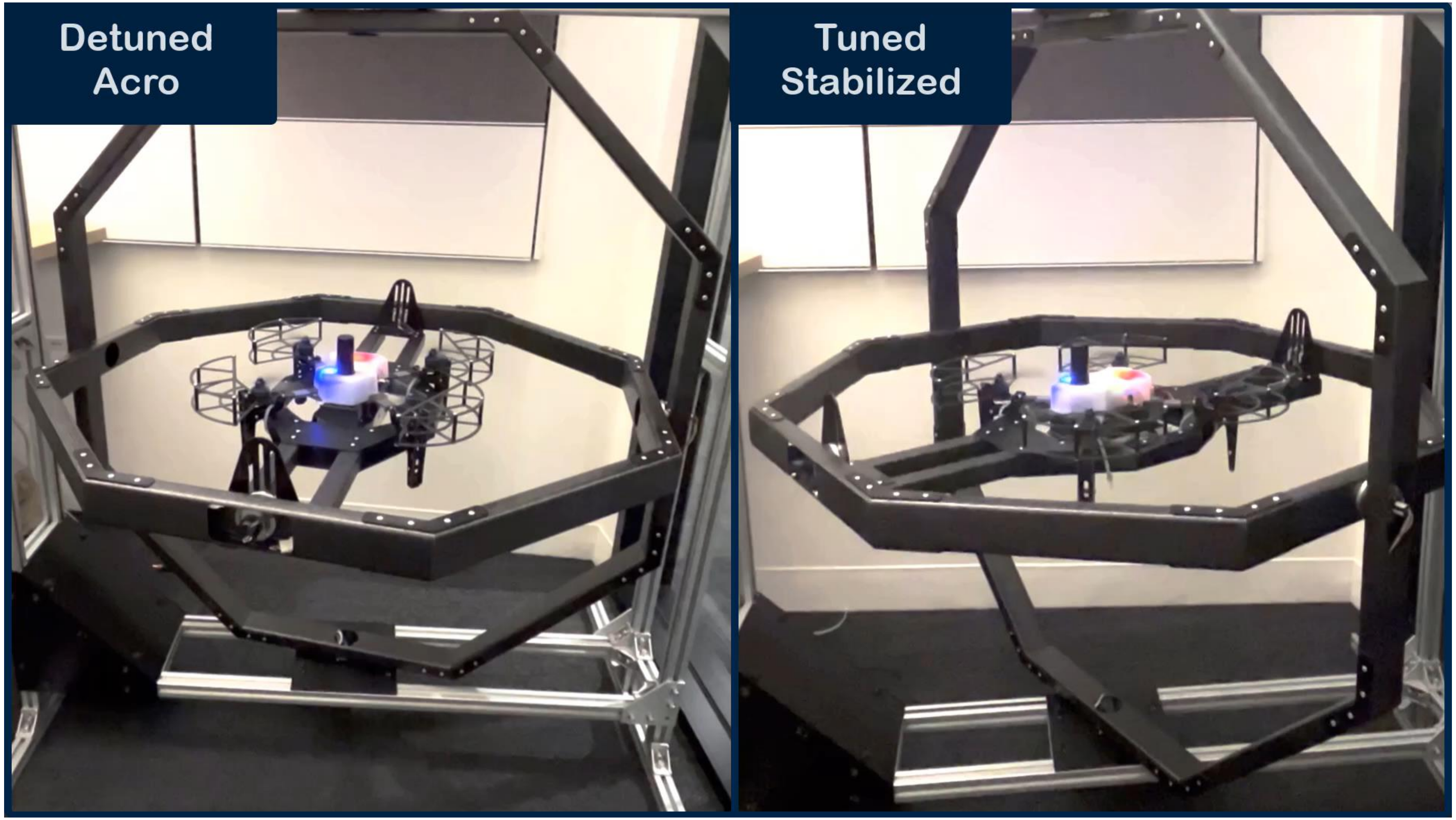
结果


UAV Animation
Body X axis
Body Y axis
Body Z axis
Trajectory
Up
North
East
Point Cloud Viewer
Running
Simulation 3D Viewer
SafeLandingFinal_UE_2023a_June1 - Simulink prerelease use
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Figure 2

使用 HIL 仿真部署算法



控制器部署



NASA Langley Develops a Process to Quickly Deploy Custom Control Laws to Multirotor Aircraft

> "This solution made it easy to take a simulation-developed control law and implement it onto a flight vehicle. In the past, hardware integration was notoriously difficult. Now we can deploy and test a new flight controller in minutes."
>
> **G. D. Asper, B. M. Simmons, R. M. Axten, and K. A. Ackerman**
> **NASA Langley Research Center**

Project Goal

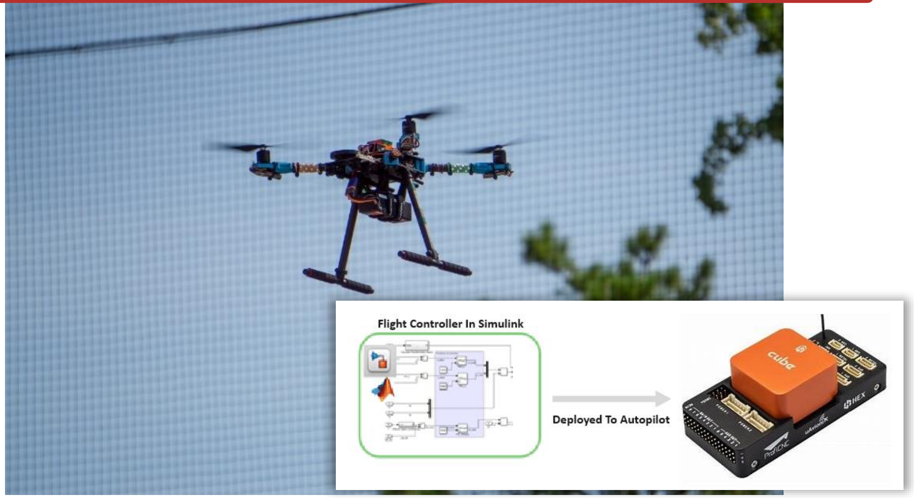
Develop a process to quickly deploy custom control laws to a multirotor aircraft, then publish the methodology to accelerate innovation in the advanced air mobility market.

Components

Simulink for developing custom control laws, with UAV Toolbox, Embedded Coder, PX4 Hardware Support Package for automatically generating deployable code for the custom control laws.

Solution

Modeled the plant in MATLAB/Simulink and ran hardware-in-the-loop simulations on a test bench. Deployed a custom flight controller to Cube Orange and Cube Blue flight computers running PX4 firmware. Investigated implementation of geofencing and return-to-launch behaviors along with a custom mixer to support the development of a subscale eVTOL aircraft. Injected programmed test inputs into the motor commands to help collect data for plant model identification. Tested and refined multiple control architectures at indoor and outdoor NASA flight-test facilities.



Credit: NASA Langley Research Center

Market accelerator

Plans to publish methods used and provide publicly available data to accelerate the emerging advanced air mobility market.

Testing completeness

Tested a multirotor aircraft in free flight with multiple control architectures and programmed test input injection.

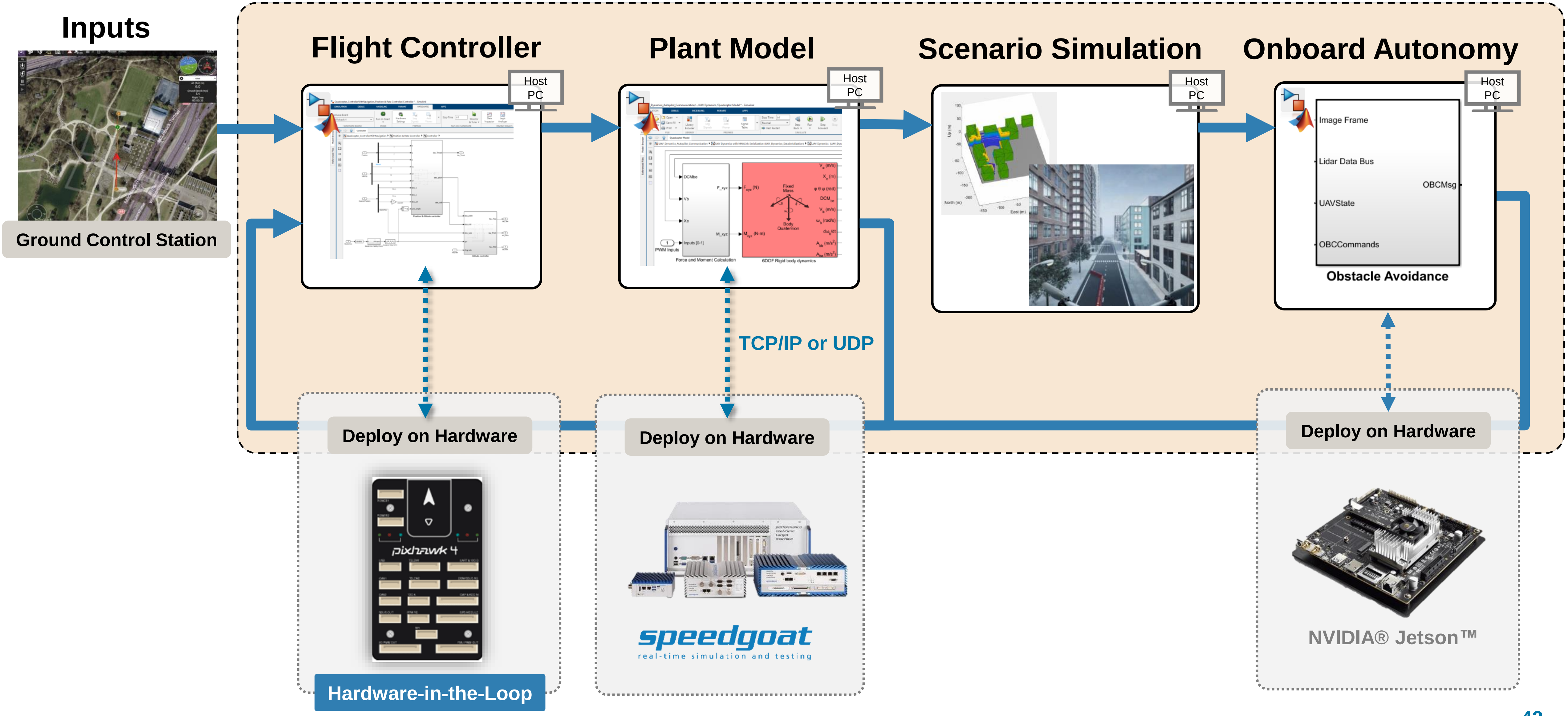
Time savings

New methodology reduced the time it takes to integrate and flight-test a new controller from weeks to minutes.

» **Learn more about NASA's VTOL Aircraft Testing Framework**

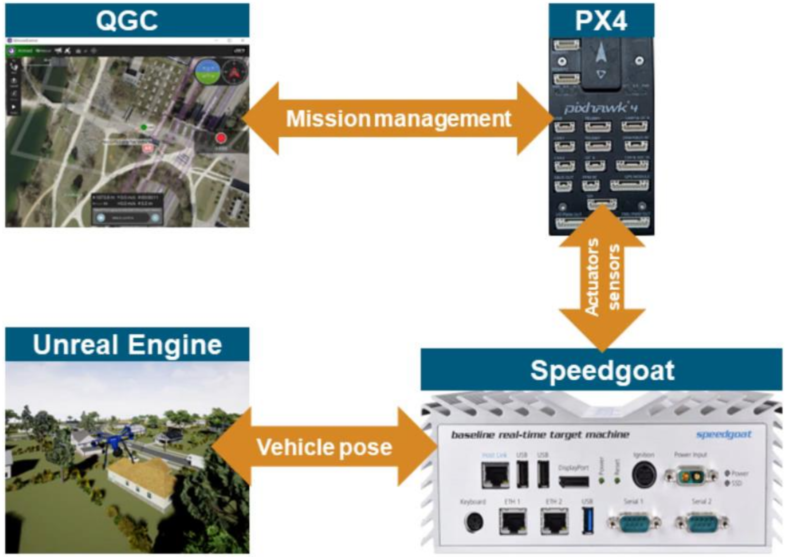
NASA 使用 Simulink 部署的控制器进行试飞

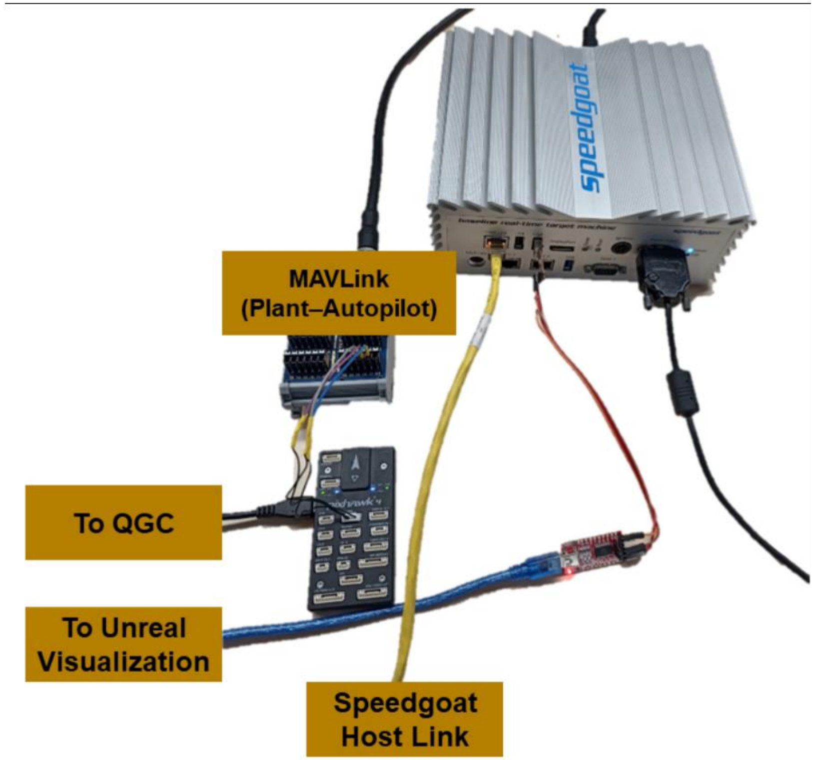
具有实时HIL仿真的设计自主算法




Scene
Sensor
Image
Location
Orientation
Simulation 3D Scene Configuration
Simulation 3D Fisheye Camera
UAV
Joystick Input
goat
simulation
testing

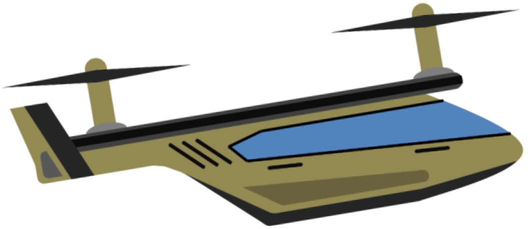
传感器故障

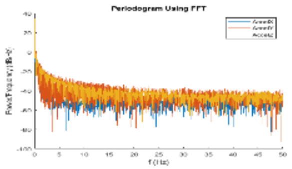


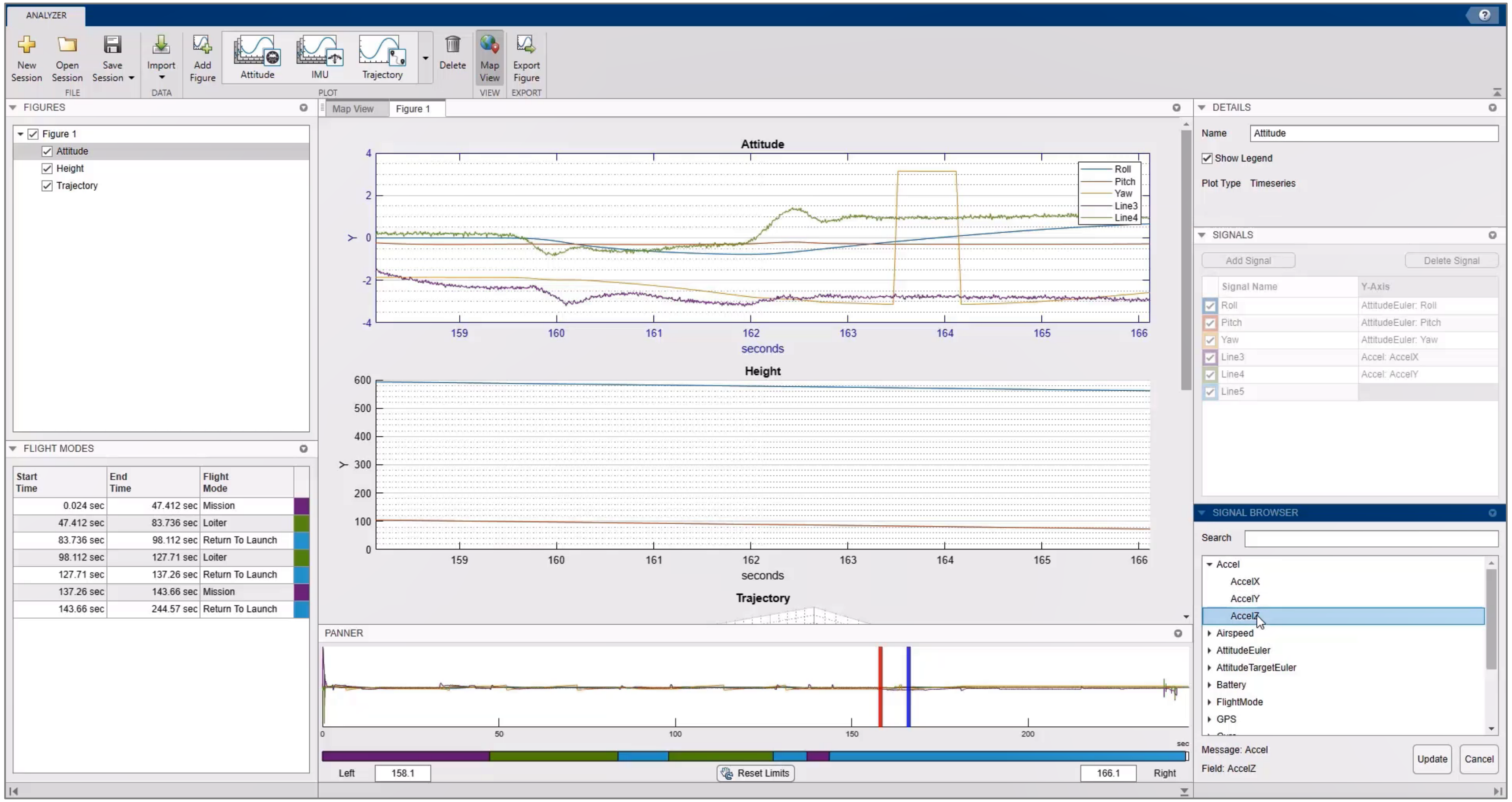


Hardware In Loop Simulations
(PX4 Autopilot & Speedgoat Plant)

飞行数据分析

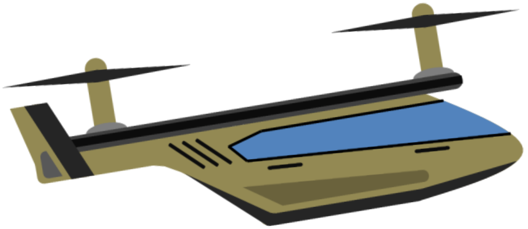


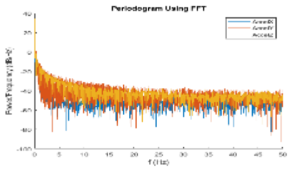


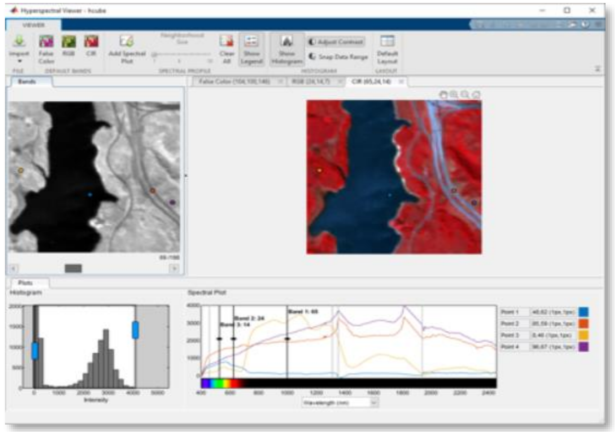


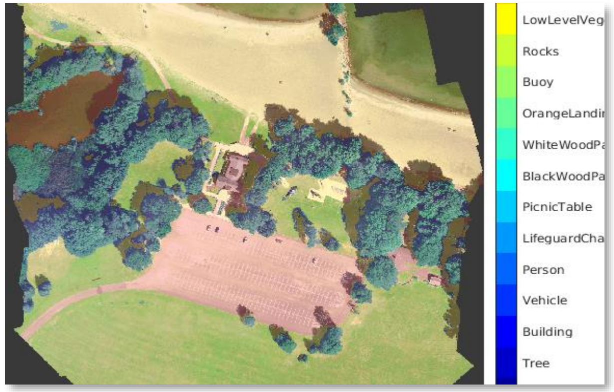
飞行日志分析工具，用于评估无人机飞行性能，并通过详细分析识别潜在差异

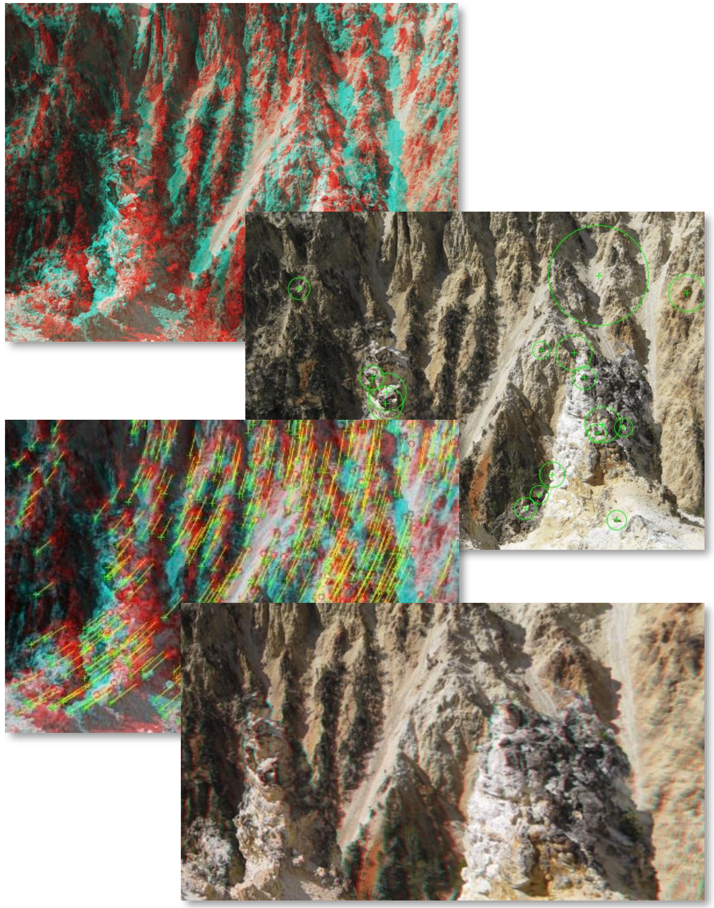
飞行数据分析





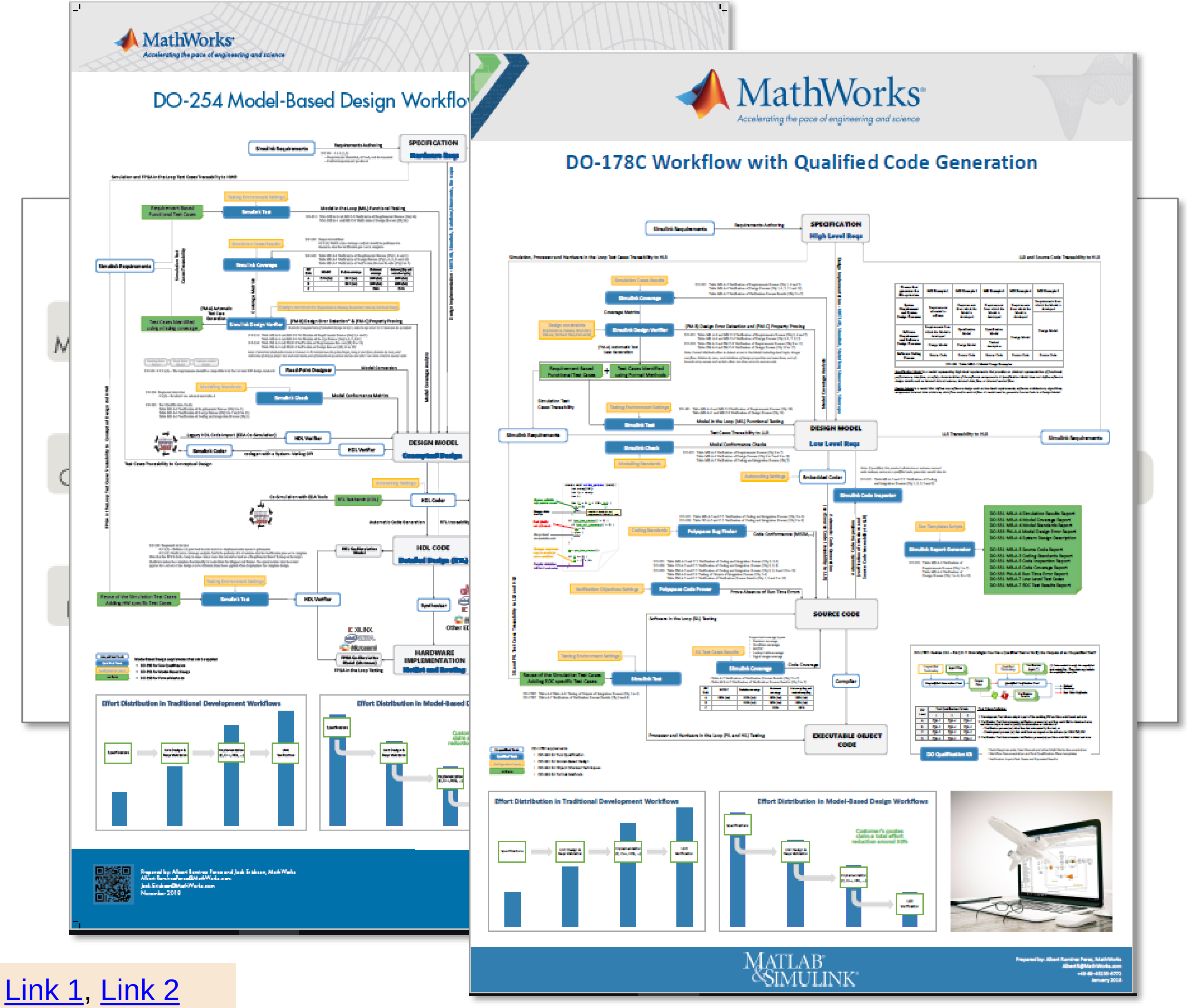


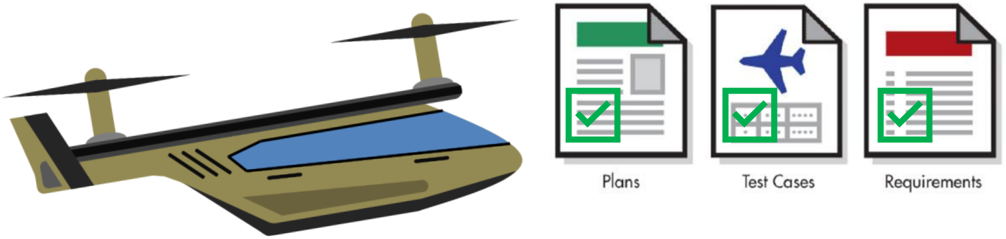




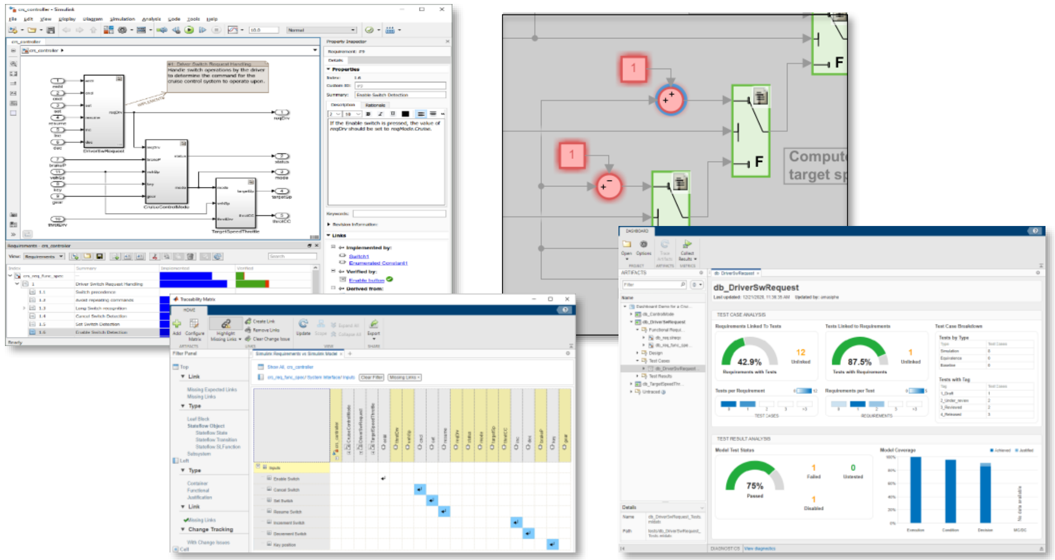
用于特定无人机应用（例如测量、测绘等）的传感器有效载荷数据后处理

适航认证的支持



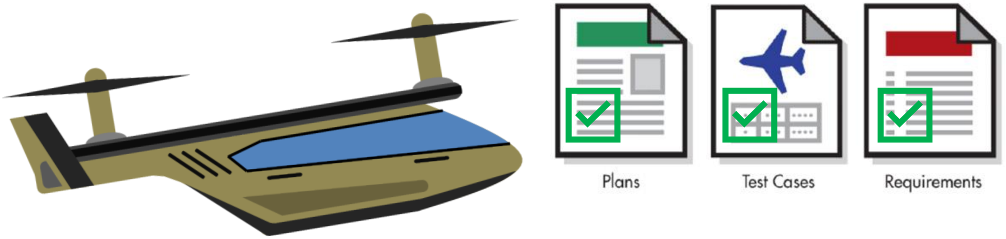


具有广泛验证工具的成熟认证标准开发工作流程



[Link 1], [Link 2]

适航认证的支持



MathWorks

Korean Air Speeds UAV Flight Control Software Development and Verification with Model-Based Design

Challenge
Develop and verify flight control software for unmanned aerial vehicles

Solution
Use Model-Based Design to design and simulate flight control laws and operational logic, generate and verify production code, and conduct HIL tests

Results
- 100% of run-time errors in handwritten code identified and eliminated
- Development effort reduced by 60%
- Costly flight tests minimized


A Korean Air unmanned aerial vehicle.

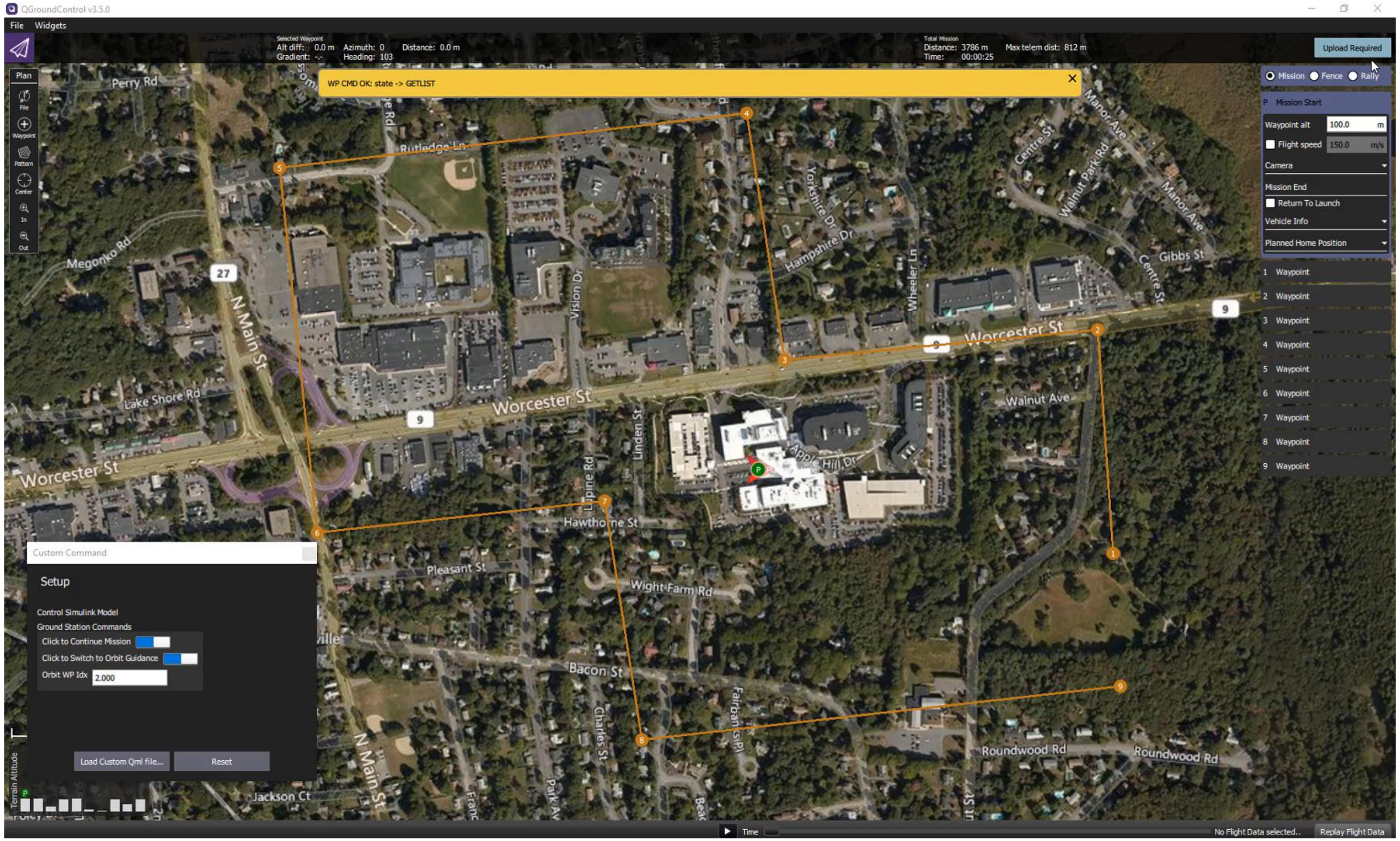
"The model reuse and efficiency improvements enabled by MATLAB and Simulink save time and lower costs. We estimate a time savings of more than 50% is achievable with Model-Based Design compared with hand-coding, and the advantages of Model-Based Design increase with the complexity of the project."
- Jungho Moon, Korean Air

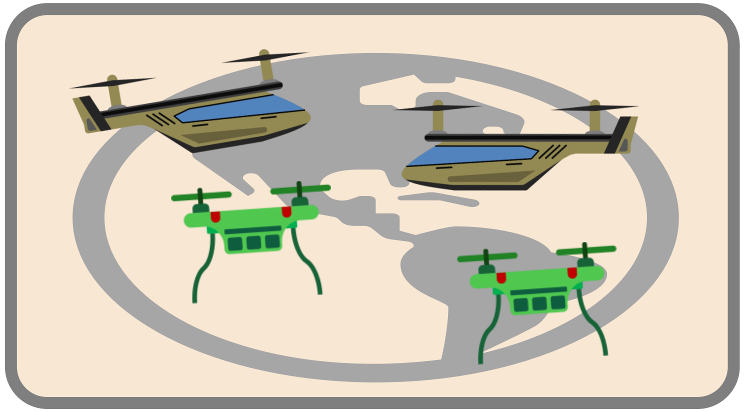
[Link to user story](#)

21

在硬件测试之前利用自动验证功能评估无人机设计

运营管理

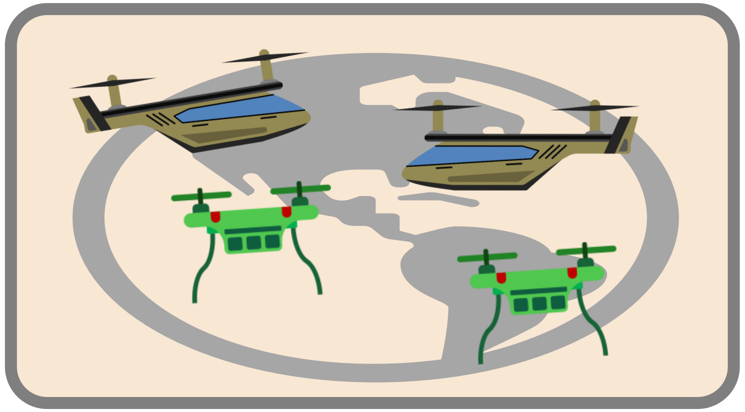


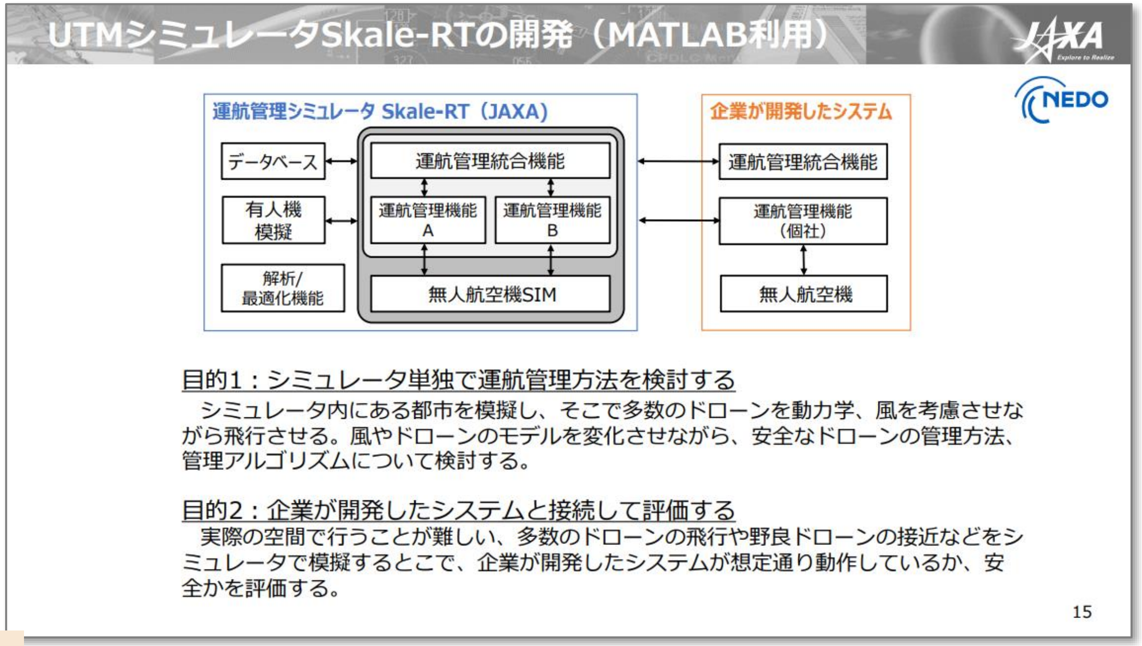


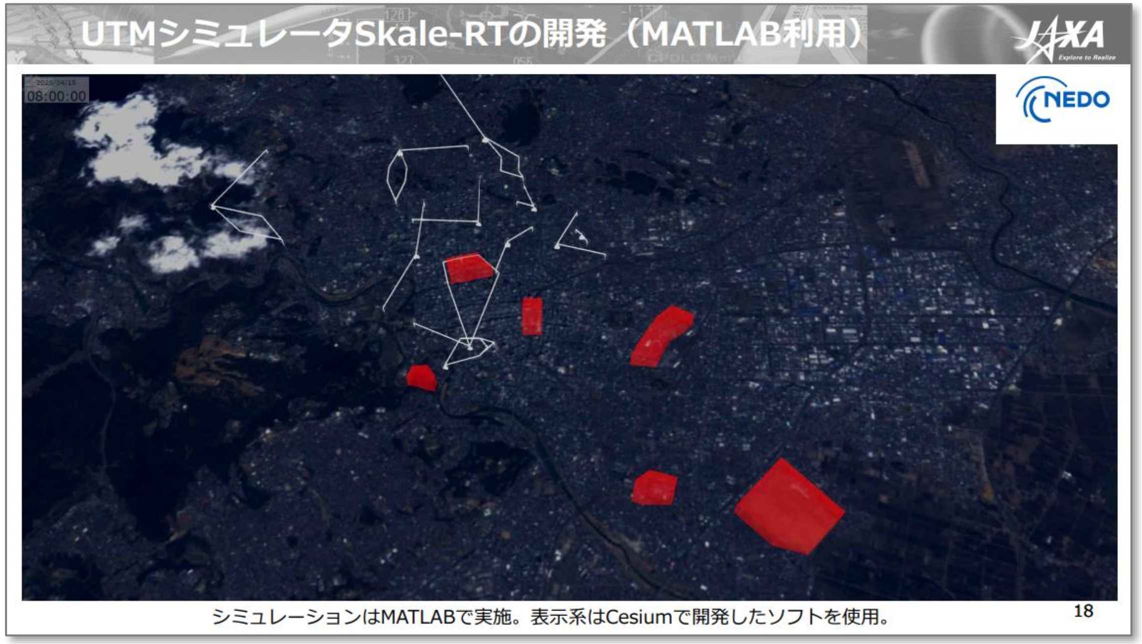
连接到地面控制软件以定义任务并监控飞行

运营管理

Multi-UAV simulations with parallel computing technologies

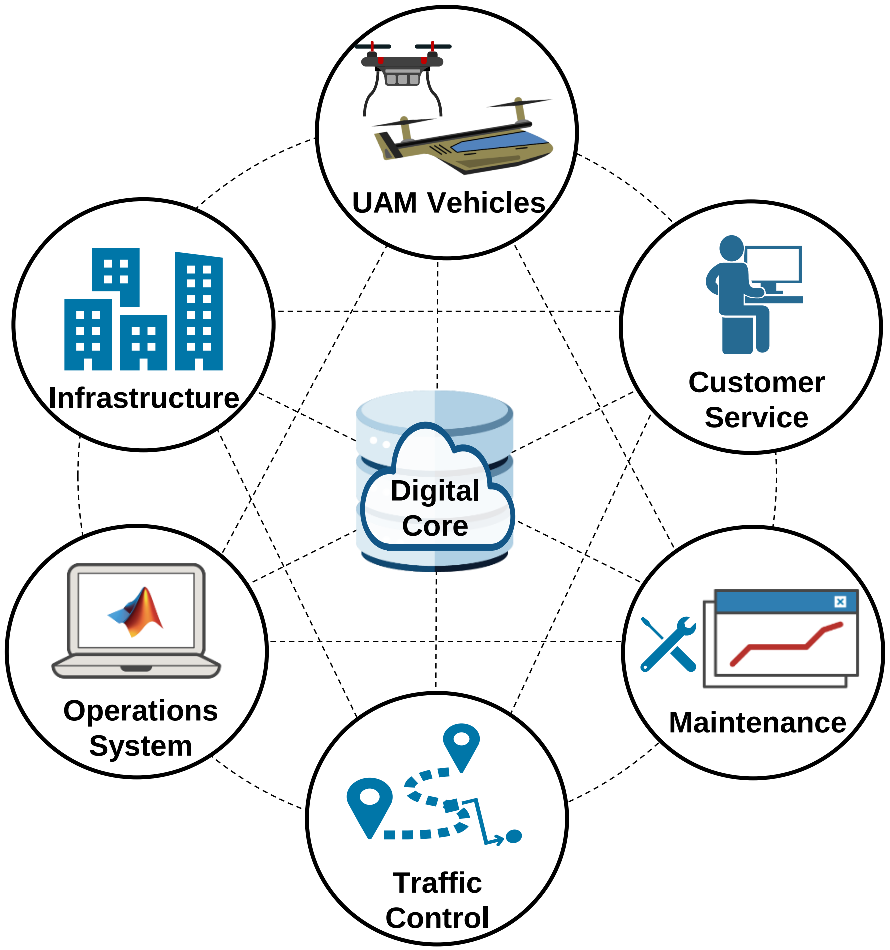






Link

使用 MATLAB 和 Simulink 进行 UAM 开发



Innovative Urban Air Mobility with MATLAB/Simulink:

- Develop UAM systems
- Incorporate autonomy
- Leverage big data
- Design AI algorithms
- Deploy applications

…

MATLAB EXPO

Thank you

MathWorks®